# FINAL REPORT

# DEVILS LAKE UPPER BASIN STORAGE EVALUATION

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**Prepared For:**

**ST. PAUL DISTRICT**
**U.S. ARMY CORPS OF ENGINEERS**

**Submitted By:**


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# EXECUTIVE SUMMARY

The Devils Lake Upper Basin Storage Evaluation was conducted for the U.S. Army Corps of Engineers, St. Paul District, by WEST Consultants, Inc., and Polaris Group, Inc. The primary purpose of this study is to assess the impacts of upper basin storage restoration alternatives on the inflows to Devils Lake. The upper basin storage alternative under consideration is the restoration of "drained" depressions. A vast amount of geographic and historical data was collected to (1) delineate and classify the depressions, and (2) develop a physically-based hydrologic model to simulate the hydrologic functions of the depressions.

Given the limitations in the available data and other project constraints, some simplifications and assumptions were made during the analysis. These assumptions were appropriate given the objective and time constraints of this study. Since the results of this study indicate that depression restoration can reduce the volume of runoff entering Devils Lake, further studies should be conducted to more accurately quantify the runoff reduction resulting from depression restoration. A summary of the results and recommendations for future studies are presented in the following sections.

## DEPRESSION DELINEATION AND CLASSIFICATION

Depressions were delineated and classified for the entire 2,616 square mile upper basin watershed (exclusive of Stump Lake and local Devils Lake drainage area). A digital elevation model (DEM) was used to determine the location, area, and volume of depressions in the upper basin subwatersheds. Using the flow chart in Section 3 (see Figure 3-1), the depressions were categorized as *possibly intact*, *possibly drained*, *lake* or *other* based on aerial photos, National Wetlands Inventory (NWI) data, flow direction data, and digital quad maps. The modifier "possibly" was added to the "intact" and "drained" classifications because field verification was not performed during this study. Depressions that were not captured by the DEM were added and classified based on the aerial photos and NWI data. It should be noted that the NWI wetland definition and the resulting NWI polygons do *not* include depressions that were completely drained prior to 1979. Therefore, any completely drained depressions not captured by the DEM nor by the NWI data are not incorporated into the data set. The average depth (and volume) for each of the non-DEM depressions was estimated based on an average depth-area relationship developed from all of the DEM-derived depressions. A comprehensive quality assurance review of the classified depressions was conducted for the entire upper basin. The results of the classifications were compared to previous studies.

The depressions described as "possibly drained" in this report may be fully drained, mostly drained, partially drained, likely drained (i.e., appears drained, but not definitively so), filled-in, or otherwise non-intact or non-functional. The clear presence of a man-made drain was not a prerequisite for classifying a depression as "possibly drained". In a similar manner, depressions labeled as "possibly intact" could be fully intact, mostly intact, or likely intact (i.e., appears intact, but not definitively so). The presence of standing water was not a prerequisite for classifying a depression as "possibly intact" because water in a shallow depression could be fully lost to evaporation. A summary of the possibly intact and possibly drained depressions identified in this study is included in the following table:

| Depression Type | Count | Area (acres) | Volume (acre-ft) |
|---|---|---|---|
| Possibly Intact [1, 2] | 63,458 | 201,990 | 481,604 |
| Possibly Drained [1, 3] | 52,210 | 92,429 | 132,729 |
| *Total* | *115,668* | *294,419* | *614,333* |

Notes:

(1) Based upon the available data and classification procedure, these depressions were classified as either "intact" or "drained". However, because field verification was not performed, the modifier "possibly" was adopted.

(2) "Possibly intact" depressions may be fully intact, mostly intact, or likely intact (i.e., appears intact, but not definitively so). The presence of standing water was not a prerequisite for classifying a depression as "possibly intact" because water in a shallow depression could be fully lost to evaporation.

(3) "Possibly drained" depressions may be fully drained, mostly drained, partially drained, likely drained (i.e., appears drained, but not definitively so), filled-in, or otherwise non-intact or non-functional. The clear presence of a man-made drain was not a prerequisite for classifying a depression as "possibly drained".

Due to the comprehensive nature of the depression delineation and classification process, the results given in the above table represent very reasonable estimates of upper basin depression area and volume. Overall, however, the estimates of intact and drained depression area and volume totals are believed to be conservative (i.e., underestimated) to some degree for the following reasons: (1) the added NWI polygons do not represent the maximum depression area; (2) a number of DEM depression polygons appeared to be smaller in area than the corresponding depressions on the aerial photos (The underestimated area and volume from the DEM was only partly offset by the presence of larger-than-appropriate DEM depression polygons); and (3) there were areas, especially within the 10-foot contour interval region, where depressions were missed by both the DEM grid and the NWI data set. For these reasons, it is likely that a more intensive analysis would result in a greater number of depressions.

Although the depression delineation and classification conducted during this study were extensive and detailed, there were some limitations to the methods. These limitations, with varying degrees of importance, include the following: (1) no field verification was conducted due to time constraints and the presence of snow cover during the study period; (2) partial drainage was not accounted for; (3) some individual depression classifications are subject to interpretation; (4) classification was based upon aerial photos representing one point in time; (5) a small number of the aerial photos were darker than normal, making the depressions more difficult to categorize; and (6) the resolution of the aerial photos was not fine enough to identify the location of fully drained depressions not captured by the DEM nor the NWI data and the location of some of the drainage ditches.

While there are some limitations to the classification process, there are also a number of important advantages of this classification process, including: (1) depressions were individually delineated and classified over the entire upper basin watershed; (2) physically-based delineation was conducted using the DEM, thus minimizing the need for extrapolation; (3) visual verification of depressions using aerial photos was utilized; (4) supplementary data (NWI, quad maps, flow direction) was incorporated; and (5) quality assurance/quality control was performed.

The accuracy of the delineation and classification of some of the individual depressions was limited by the available data and project constraints. For future studies, it is recommended that this work be refined as follows:

- Obtain historical aerial photos, preferably from the 1950's when drainage activity was minimal, to assist in identifying depressions in those areas missed both by the DEM grid and NWI data. These historical photos could also be compared to current photos to verify the depression classification.

- Perform extensive field verification to locate drainage ditches, determine the functionality of the farmed depressions, and verify the depression classification.

- Utilize the 1997 color infrared photography, which is higher resolution than the DOQ's used in this study, to refine the depression delineation and classification, but this would be very labor intensive because the data is not available in digital format.

- Obtain more refined soil data to develop relationships between depression area and hydric soils.

- Include more classifications such as "partly drained". Separate depressions that have drainage ditches from those that have been disturbed by other activities such as farming.

- Obtain higher resolution digital terrain data, especially in those areas currently modeled from the 10-foot contour interval data.

## HYDROLOGIC MODEL

Originally, the hydrologic model of the Devils Lake basin was going to be developed using the HEC Hydrologic Modeling System (HEC-HMS), Version 2.1.1 (Hydrologic Engineering Center, U.S. Army Corps of Engineers, 2001). However, it was determined that the HEC-HMS model could not reasonably be configured to adequately model the hydrologic function of the depressions. Therefore, a custom hydrologic model, the Pothole-River Networked Watershed Model (PRINET), was developed to simulate the depression storage, soil storage, and runoff in the Devils Lake basin. The PRINET application was written in Microsoft Visual Basic 6.0 (Visual Basic For Applications) inside a Microsoft Access database. The model used geographic data to develop the drainage patterns and subbasins. Most of the hydrologic calculations use the same algorithms as HEC-HMS.

Six subwatersheds, encompassing the upper basin of Devils Lake, were modeled by PRINET (see Figure 5-1, in Section 5). Each subwatershed was divided into numerous subbasins. There were 9,078 subbasins modeled in the upper basin and the average subbasin area was 0.29 square miles. The subbasins in each subwatershed were networked; that is, the exact sequence of flow between subbasins was specified for each subwatershed.

The computational sequence and the hydrologic processes modeled are summarized below. The model performs the following ten computations on daily basis:

1. Determine precipitation and evaporation for each day.
2. Add precipitation to the soil moisture and to the depressions.
3. Determine infiltration of precipitation into the soil, and update the soil moisture level accordingly.
4. Any precipitation that does not infiltrate runs off into intact depression storage. A separate accounting is made of on-river depressions (those that intersect the river network) and off-river depressions (those that do not intersect the river network).
5. If upstream subwatersheds exist, they are modeled as sources of flow into the downstream subwatershed model at the appropriate location.
6. Evaporation is calculated for each subbasin's intact depressions and the water storage volume is reduced accordingly.
7. Evapotranspiration is calculated for each subbasin's soil and the moisture level is reduced accordingly.
8. Percolation is determined for subbasins where the soil is sufficiently saturated to permit percolation.
9. When the depression water volume of a subbasin's off-river depression storage exceeds the off-river depression storage capacity, the excess runs off into the on-river intact depression storage of the same subbasin.
10. When depression water volume of a subbasin's on-river depressions exceeds depression storage capacity, the water flows into the intact on-river depression storage of the next downstream subbasin, or to the outlet of the subwatershed if there are no downstream subbasins.

## HYDROLOGIC MODEL CALIBRATION

The PRINET model was calibrated to historic streamflows. The Devils Lake upper basin was divided into 12 different regions for calibration based on subwatershed boundaries and the location of streamflow gages. Since wetland drainage was allowed before the implementation of the wetland conservation provisions (i.e., "Swampbuster") in 1985, the amount of intact depression storage would be different before and after 1985. Therefore, the PRINET model calibration period was conducted for water years 1985 through 1999, a period with minimal changes to the depression topography and drainage network found in the upper basin. However, in order to provide a sufficient warm-up period, the model runs started on October 1, 1978 (start of water year 1979).

The overall calibration approach included the following primary objectives: (1) matching the total computed and observed volumes to within approximately one to two percent for the entire calibration period (1985-99), and (2) matching the pattern of dry, low runoff years in the late 1980s and the wet, high runoff years in the mid-to-late 1990s. The same hydrologic parameters were used for the entire calibration period; no parameters were varied annually to account for year-to-year differences. The number of parameters varied by calibration region was kept to a minimum.

## ALTERNATIVE ANALYSIS

Eleven climatic scenarios were used to simulate future conditions with and without depression restoration. Possibly drained depressions having an average depth of greater than or equal to 0.5 feet were candidates for restoration. There were 13,464 restoration candidates (26 percent of the total number of possibly drained depressions) having a total surface area of 79,762 acres (86 percent of the total possibly drained depression surface area) and a total volume of 127,835 acre-feet (96 percent of the total possibly drained depression volume). Different levels of restoration (25, 50, 75, and 100 percent by volume of the restoration candidates) were analyzed.

Depressions were restored in each subwatershed. Each subwatershed had the same percentage of restored volume as the corresponding restoration scenario. For example, for 50 percent restoration (Scenario C), 50 percent by volume of the possibly drained depressions from Comstock was restored and 50 percent by volume of the possibly drained depressions from Starkweather was restored and so forth for each subwatershed.

The scenarios were constructed by **randomly** selecting depressions that had been classified as possibly drained and converting these depressions to possibly intact. The selection process was not optimized by drainage area or location. To construct the 25 percent restoration scenario model (Scenario B), enough restoration candidate depressions were randomly chosen in each subwatershed modeled until 25 percent of the total volume of restoration candidates was achieved for that subwatershed. These were converted to possibly intact depressions. To construct the 50 percent restoration scenario model (Scenario C), additional depressions, randomly selected, were added to this set until 50 percent of the total restoration volume was achieved for each subwatershed. The 100 percent restoration scenario (Scenario E) models had all restoration candidates reclassified as possibly intact.

The surface area and volume of the restored depressions for the different restoration levels are summarized in the following table:

| RESTORATION LEVEL | 25% (Scenario B) | 50% (Scenario C) | 75% (Scenario D) | 100% (Scenario E) |
|---|---|---|---|---|
| Area Restored, acres | 19,472 | 39,681 | 59,872 | 79,762 |
| Volume Restored, acre-ft | 31,431 | 63,608 | 94,850 | 127,835 |

When a depression was restored, the total depression volume to the pour point was restored. Though not considered in this study, additional volume could be retained in each depression by constructing berms, gated structures, or tie backs to higher ground. Since the contributing drainage areas are modeled for each of the depressions (see Section 4), only the runoff from the area that drains to the depression fills the depression. Some depressions may have large contributing areas that may cause overtopping whereas some depressions may not. Depending on the depression surface area and evaporation rate, the amount of storage carry-over from year to year will vary with the depression characteristics. Generally, the annual available depression storage is less than the total depression storage.

The annual flow reductions resulting from depression restoration vary significantly for individual water years. In dry years, the percent of flow reduction is larger than in wet years. The following table shows the average annual flow reduction for each restoration scenario and climate sequence. The average annual runoff reduction is less than the restored volume.

| | | **No Restoration** | | **Restoration Level** | | | |
|---|---|---|---|---|---|---|---|
| | | | | **25%** (B, 31,431 acre-ft and 19,472 acres restored) | **50%** (C, 63,608 acre-ft and 39,681 acres restored) | **75%** (D, 94,850 acre-ft and 59,872 acres restored) | **100%** (E, 127,835 acre-ft and 79,762 acres restored) |
| **Climate Sequence** | **Water Years** | **Total Runoff** (acre-ft) | **Average Annual Runoff** (acre-ft) | **Average Annual Runoff Reduction** (acre-ft) | | | |
| 001 | 2003-2020 | 3,101,720 | 172,318 | 7,294 | 14,007 | 20,754 | 27,173 |
| 002 | 2003-2020 | 2,017,254 | 112,070 | 7,058 | 13,496 | 18,737 | 23,702 |
| 003 | 2003-2020 | 1,688,607 | 93,812 | 6,714 | 12,653 | 17,729 | 23,056 |
| 004 | 2003-2020 | 1,292,294 | 71,794 | 6,150 | 11,704 | 16,909 | 21,638 |
| 005 | 2003-2020 | 2,888,905 | 160,495 | 7,869 | 15,246 | 22,303 | 29,533 |
| 006 | 2003-2020 | 1,279,228 | 71,068 | 5,661 | 10,185 | 14,174 | 18,291 |
| 007 | 2003-2020 | 2,259,557 | 125,531 | 7,395 | 14,013 | 19,727 | 25,404 |
| 008 | 2003-2020 | 1,594,247 | 88,569 | 6,601 | 12,802 | 18,098 | 23,328 |
| 009 | 2003-2020 | 1,632,394 | 90,689 | 7,151 | 12,881 | 18,089 | 23,545 |
| 010 | 2003-2020 | 2,051,472 | 113,971 | 6,464 | 12,111 | 17,511 | 22,745 |
| Average | | 1,980,568 | 110,032 | 6,836 | 12,910 | 18,403 | 23,841 |
| As Percent of Restored Volume | | | | 22% | 20% | 19% | 19% |
| Runoff Reduction Volume / Area Restored | | | | 4.2 in | 3.9 in | 3.7 in | 3.6 in |
| WET | 2003-2035 | 8,737,679 | 264,778 | 7,959 | 15,643 | 23,502 | 31,193 |
| As Percent of Restored Volume | | | | 25% | 25% | 25% | 24% |

One method of presenting the impact of restoration on runoff reduction is by evaluating the ratio of the reduction in annual runoff volume to the area restored. For example, for the 25 percent restoration level (B), the average runoff reduction is 6,826 acre-ft. Since 19,472 acres were restored, this yields 6,826 acre-ft / 19,472 acres = 0.35 feet = 4.2 inches. This value primarily represents the difference between storage and evaporation in the restored depressions and the percolation and evapotranspiration from the soil area before restoration. It does not represent the average evaporation from a depression, which was approximately 20 or more inches per year.

The PRINET model did not include a soil moisture algorithm beneath the depressions. Instead, the depressions were modeled as hard-bottom "bowls". Consequently, infiltration of water from a depression into the soil and evapotranspiration from the soil in the dry portions of a depression (when the depression was less than 100 percent full) were not modeled. Therefore, the model could be underpredicting the net total evaporation (free surface evaporation plus evapotranspiration from the soil) in the depressions.

Given the current classifications of "possibly intact" and "possibly drained" depressions, the runoff reduction values reported in this study are conservative for two reasons:

- The depressions restored in the 25, 50, and 75 percent restoration scenarios were selected randomly within each subwatershed. The restoration level was uniform across all subwatersheds (e.g., for the 25 percent restoration scenario, 25 percent by volume of the restoration candidates in the Comstock subwatershed was restored, 25 percent by volume of restoration candidates in Edmore was restored, and so forth for each subwatershed). Incremental optimization of the depressions selected for restoration was not performed. It is expected that the runoff reduction volumes would increase for the scenarios having less than 100 percent restoration if the restoration candidates were selected using an optimization routine (i.e., determine which depressions would result in the largest runoff reduction). Potential optimizations include selection by contributing drainage areas, by location (restoring depressions in subwatersheds having high runoff and a larger percentage of "possibly drained" depressions or restoring on-river depressions before off-river), and by depression size or volume.

- Since the net total evaporation from the depressions was probably underpredicted, the annual runoff reduction with depression restoration could be underestimated.

## FUTURE STUDIES

Since the results of this study indicate that depression restoration can reduce the volume of runoff entering Devils Lake, further studies should be conducted to more accurately quantify the runoff reduction resulting from depression restoration. The recommendations for the refinement of the depression delineation and classification were discussed previously.

The hydrologic model, PRINET, was developed in accordance with the study goals to simulate soil and depression storage in the Devils Lake basin. Some simplified algorithms for depression storage and evaporation, snowmelt and frozen ground were incorporated into the model. These algorithms were appropriate for this study. However, the following model refinements are recommended for more detailed analyses:

- The PRINET model did not include a soil moisture algorithm beneath the depressions. Instead, the depressions were modeled as hard-bottom "bowls". Consequently, infiltration of water from a depression into the soil and evapotranspiration from the soil in the dry portions of a depression (when the depression was less than 100 percent full) were not modeled. Therefore, the model could be underpredicting the net total evaporation (free surface evaporation plus evapotranspiration from the soil) in the depressions. A soil moisture accounting algorithm with infiltration and evapotranspiration should be added to the model.

- The Devils Lake evaporation was applied to the depression. Since the depressions are significantly smaller water bodies, the depression evaporation may differ from the Devils Lake evaporation. Some evaporation measurements for different depression sizes would be useful in determining the rate of evaporation from the depressions compared to pan evaporation measurements and the evaporation from Devils Lake.

- A relationship of surface area versus storage was developed for the depressions. This relationship was in the envelope of area-storage curves provided for several of the upper basin lakes. The digital elevation models could be used to refine the area-storage relationships of the depressions.

- The degree-day method was used to simulate snowmelt in PRINET. A more rigorous energy budget algorithm could be developed if the required data are available.

- An infiltration/season break was incorporated in the model to simulate frozen and unfrozen ground conditions (i.e., low and high infiltration conditions). A 30-day moving average of the average daily temperature is used to transition between the two conditions. The volume of runoff is very sensitive to the infiltration break. A more physically-based algorithm should be incorporated into the hydrologic model.

If the hydrologic model is modified, the model must be re-calibrated to observed data before it is used to evaluate depression restoration.

For the restoration scenarios with less than 100 percent depression restoration, the restoration candidates were selected randomly within each subwatershed. Incremental optimization of the depressions selected for restoration was not performed. It is expected that the runoff reduction volumes associated with depression restoration would increase if an optimization routine was used to select the depressions for restoration. Potential optimization parameters are contributing drainage area, depression location, depression size or depression volume.

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# 1. INTRODUCTION

## 1.1. BACKGROUND

Devils Lake (including Stump Lake) is a terminal lake located in a 3,858 square mile drainage area in northeastern North Dakota. The Devils Lake basin and associated subwatersheds are shown in Figure 1-1. Approximately 3,373 square miles drains to Devils Lake and the remaining 485 square miles to Stump Lake. The drainage areas of the subwatersheds are listed in Table 1-1.

The geologic features of The Devils Lake basin are primarily a result of the depositional and erosional effects of continental glaciation. The eastern, western and northern boundaries of the Devils Lake basin are poorly defined low divides (Wiche and Pusc, 1994). The southern boundary is comprised of a series of recessional moraines that lie between Devils Lake and the Sheyenne River (Wiche and Pusc, 1994).

In the eastern portion of the Devils Lake basin, Edmore Coulee is the principal tributary to the Sweetwater-Morrison Lakes. When the Sweetwater-Morrison Lakes fill to their outlet, water flows through Webster Coulee into Dry Lake. Webster Coulee and Starkweather Coulee are the primary tributaries to Dry Lake. Flows from Dry Lake to Channel A are regulated by an adjustable head gate control. Channel A flows into Sixmile Bay, which is part of Devils Lake.

St. Joe Coulee drains to Mikes Lake. Chain Lake receives inflow from Mikes Lake and Calio Coulee. Chain Lake spills into Lake Alice, which also receives inflow from Mauvais Coulee. A channel connects Lake Alice to Lake Irvine. Lake Irvine has an outlet to Big Coulee. The Hurricane Lake subwatershed drains through Little Coulee to Big Coulee downstream of Silver Lake and Lake Irvine. Downstream of the confluence with Little Coulee, Big Coulee flows through Pelican Lake to Devils Lake. Comstock drains directly to Devils Lake.

Table 1-1. Drainage areas for the Devils Lake subwatersheds.

| Subwatershed | Drainage Area ($mi^2$) |
|---|---|
| Edmore | 595 |
| Starkweather | 320 |
| St. Joe | 125 |
| Calio | 129 |
| Mauvais Coulee | 1,010 |
| Hurricane Lake | 372 |
| Comstock | 65 |
| Devils Lake | 757 |
| Stump Lake | 485 |

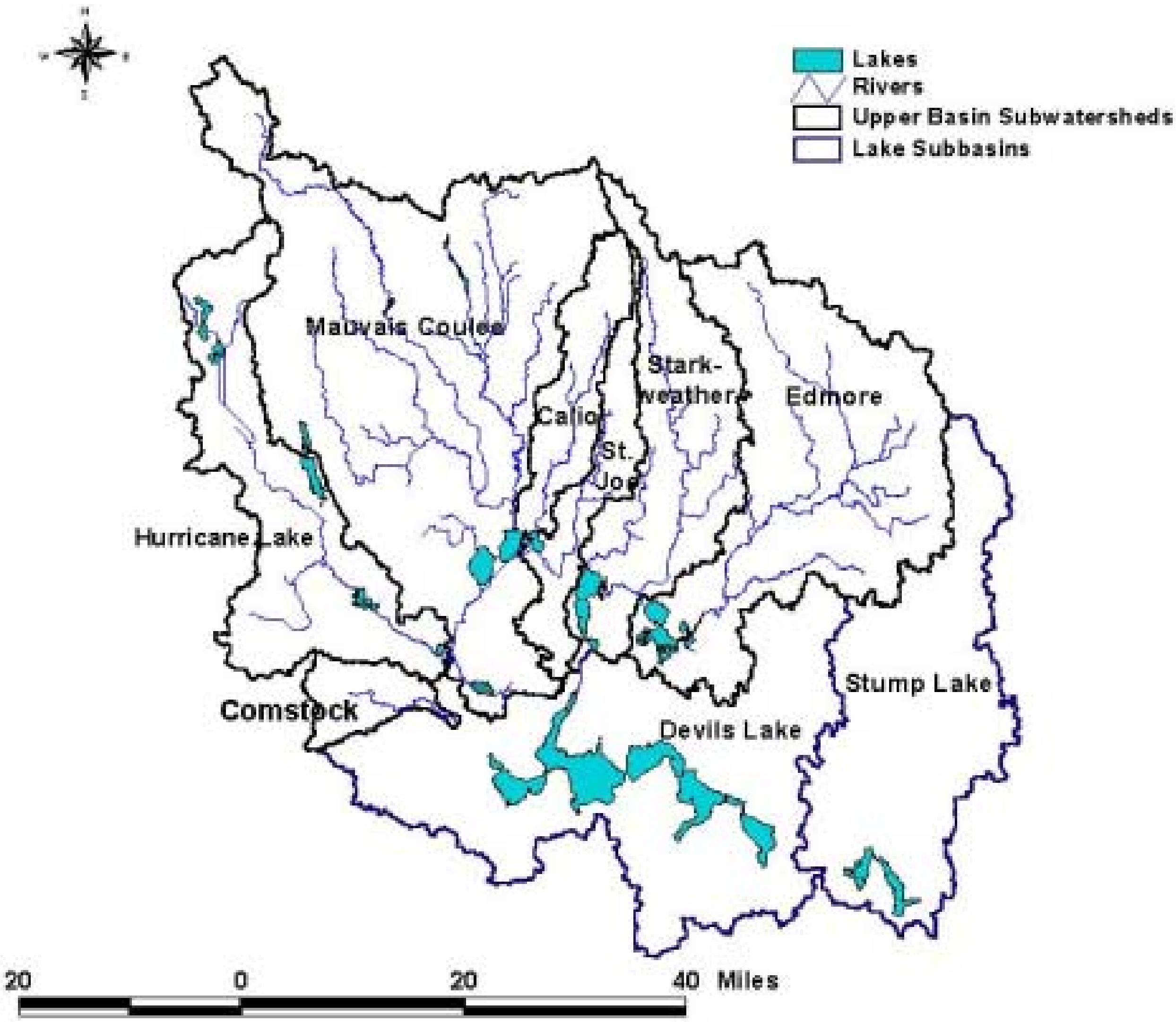



Figure 1-1. Schematic of the Devils Lake basin and subwatersheds.

Geologic records indicate that Devils Lake has experienced ongoing and periodic fluctuations in water level for at least the last four thousand years. Analysis of the historic water surface elevation of Devils Lake shows that the lake surface was at about elevation 1,438 feet mean sea level (msl) in 1867, and fell fairly steadily until 1940, reaching elevation 1,401. Generally, the lake level rose during the years 1940 to 1956, declined from 1956 to 1968, rose again to peak at an elevation of 1,428 in 1983 and 1987, and declined briefly through 1992 to an elevation of 1,425. The lake has had three separate incidences since 1950 where the water surface elevation rose about 10 feet within a period of about two years. Devils Lake reached elevation 1,447 in 1999 and is presently at elevation 1,446. At elevation 1446.5, Devils Lake spills into Stump Lake. Above elevation 1446.5, Devils Lake and Stump Lake become one large terminal lake until elevation 1459 is reached, when Stump Lake spills into the Sheyenne River. Since 1993, the lake has grown in size from 41,000 to 122,000 surface acres. The recent rise has directly inundated about 80,000 additional acres and has particularly affected many people since much of the area's development occurred during the previous period of low lake levels.

## 1.2. PROBLEM/PURPOSE

The U.S. Army Corps of Engineers (the Corps) has been tasked with developing alternatives to prevent or reduce future flood damages from rising Devils Lake water levels. Upper basin storage could be combined with other alternatives to provide an effective solution. The purpose of this study is to evaluate the impacts of upper basin storage alternatives on the volume of runoff that flows into Devils Lake as outlined in the Phase 1 Planning Report, "Devils Lake Upper Basin Storage Familiarization and Planning Study," prepared by WEST Consultants, Inc. (WEST) on November 7, 2000. During the course of the study, there were some modifications to the proposed modeling approach outlined in the Phase 1 Planning Report. The original and final modeling approaches are discussed in the following sections.

### 1.2.1. Original Modeling Approach

The hydrologic modeling approach proposed in the Phase 1 Planning Report is described in the following paragraphs. The changes from the original proposal are summarized in Section 1.2.2.

To expedite the hydraulic and hydrologic evaluation, it was proposed to build upon previous studies by developing a detailed hydrologic model within one or two subwatersheds. Correlations would be developed from that evaluation for input data and modeling parameters to create a larger, lumped parameter model of the entire Devils Lake basin. HEC-HMS would be used to model runoff from the upper basin, including existing depressions and restored depressions (in the alternatives analysis). The soil moisture accounting system in HEC-HMS would allow the input of depression storage values for each subbasin. The HEC Data Storage System (HEC-DSS) output files from HEC-HMS would be used as input to HEC-5, a reservoir model. HEC-5 would model the hydrologic water balance in the upper basin lakes and in Devils Lake. Both programs would run continuous, sequential simulations.

The goals for the proposed upper basin hydrologic and hydraulic study were as follows:

1. Develop topographic and hydrologic correlations in the selected pilot study subbasin(s) using hydrologic modeling and the high resolution 5-foot contour interval, 10-meter grid digital elevation model (DEM) for the same area.

2. Develop, calibrate and verify an existing conditions model of the Devils Lake basin.

3. Complete long-term simulations for the existing conditions with hydrologic forecasts provided by the Corps.

4. Complete long-term simulations, using the same hydrologic forecasts used in Step 3 above, with the different upper basin storage alternatives. The alternatives evaluated would encompass the range of upper basin storage estimates presented in previous studies.

5. Assess the impacts and effectiveness of the upper basin storage alternatives by comparing the model results from Steps 3 and 4.

Ideally, the entire agricultural drainage system would be incorporated into the models. However, the extent to which these systems can be modeled is limited to the data that is available at the beginning of the study. In addition, the scope of this study does not include the evaluation of current land-use programs such as ESAP. However, the results of this study could be used to identify subbasins where land conservation programs might be most effective. The models developed for this study could be modified later for a more detailed individual subbasin analysis.

### 1.2.2. Final Modeling Approach

During the initial phases of this study, it was determined that the depressions derived from the 10-meter DEM, the National Wetlands Inventory (NWI) database and 1997 digital orthoquads were sufficient to determine the location, area and volume of most of the depressions in the upper basin subwatersheds. A relationship between area and average depth for the depressions was developed to estimate the volume of those depressions that were not captured by the DEM's. No other correlations or extrapolations were used in this study.

Based upon the available data and classification procedure, the depressions were classified as "intact", "drained", "lake", or "other". However, because field verification was not performed, the modifier possibly was added to the "intact" and "drained" classifications (in addition to "lake" and "other"). The depressions described as "possibly drained" in this report may be fully drained, mostly drained, partially drained, likely drained (i.e., appears drained, but not definitively so), filled-in, or otherwise non-intact or non-functional. The clear presence of a man-made drain was not a prerequisite for classifying a depression as "possibly drained". In a similar manner, depressions labeled as "possibly intact" could be fully intact, mostly intact, or likely intact (i.e., appears intact, but not definitively so). The presence of standing water was not a prerequisite for classifying a depression as "possibly intact" because water in a shallow depression could be fully lost to evaporation. Field verification was not conducted due to time constraints and snow cover during the study period.

During meetings with the Corps and the U.S. Geological Survey (USGS), it was decided that the USGS six-box model of Devils and Stump Lakes would be used to model the lake elevations instead of HEC-5. Initially, it was decided that WEST would modify the lake box model to accept inflows from the HEC-HMS model and subsequently run the lake model to track the lake elevations for the different scenarios analyzed in the study. However, during the latter portion of the study, it was decided that the USGS, rather than WEST, would use the outflows from WEST's hydrologic model as inflows to the lake model and assess the impacts of the upper basin storage alternatives on the elevation of Devils Lake.

Originally, the hydrologic model of the Devils Lake basin was going to be developed using the HEC Hydrologic Modeling System (HEC-HMS), Version 2.1.1 (Hydrologic Engineering Center, U.S. Army Corps of Engineers, 2001). However, it was determined that the modeling approach was not sufficient for the following reasons:

- The Soil Moisture Accounting (SMA) algorithm does not adequately simulate the hydrologic function of the depressions. All depressions are lumped into one depression over an entire subbasin. This prevents a subbasin from discharging at its outlet until all of the depression volume is utilized. It also prevents any evapotranspiration from the soil until the depressions are dry. After initial trials, it was clear that this method over-predicted the hydrologic capture of depression storage and, therefore, could not be used to analyze upper basin storage in the Devils Lake basin.

- Reservoir elements could be used to model the depression storage. However, HEC-HMS does not apply precipitation or evaporation to the reservoir elements. Therefore, additional subbasin elements and diversion elements would need to be added to account for precipitation and evaporation on the reservoirs. The elements and associated inputs must be input manually into HEC-HMS. The average subbasin size is one square mile, with a total of 2,618 subbasins. Manual model construction was extremely time consuming for a hydrologic model of this magnitude and was not feasible under the project time constraints.

- HEC-HMS does not have a frozen ground algorithm. Since snowmelt is a major component of the annual runoff in the Devils Lake basin, a method had to be developed to simulate snowmelt on frozen ground. Two HEC-HMS models were set up for each subwatershed to simulate frozen ground and unfrozen ground conditions. Therefore, because of the manual entry of data into the models, and inefficiency of starting/stopping the simulations to utilize different HEC-HMS models and capture the starting and ending states, the HEC-HMS modeling could not be completed within the project's time limit.

Because of these limitations and difficulties, HEC-HMS, in essence, had to be programmed from the outside, and tricked into modeling the processes in the Devils Lake basin. Consequently, a custom hydrologic model, the Pothole-River Networked Watershed Model (PRINET), was developed to simulate the depression storage, soil storage, and runoff in the Devils Lake basin.

The PRINET model was calibrated to historic streamflows. Eleven climatic scenarios were used to simulate future conditions with and without depression restoration. Possibly drained depressions having an average depth of greater than or equal to 0.5 feet were candidates for restoration. Different levels of restoration (25, 50, 75, and 100 percent by volume of the restoration candidates) were analyzed.

The upper basin storage alternative under consideration is the restoration of drained depressions. Due to lack of data, the storage capacity of the upper basin lakes was not explicitly modeled. However, since the total volume of additional storage capacity that could be derived from the upper basin lakes is within the range of volumes analyzed for depression restoration, the effects of increasing storage in the upper basin lakes are bracketed by the results of depression restoration scenarios.

## 1.3. REPORT OUTLINE

The project meeting summaries and acknowledgements are included at the end of Section 1. The data collected and utilized during the study are described in Section 2. Section 3 details the depression delineation and classification process and results. A comparison to other studies is also included. The PRINET model is described in Section 4. Appendix A contains a more detailed technical description of the model. The PRINET calibration to existing conditions and historical streamflows is presented in Section 5. The results of the depression restoration scenarios are highlighted in Section 6, and recommendations for future studies are included in Section 7. The attached appendices include more detailed information and model output.

## 1.4. PROJECT MEETINGS

The minutes of the following project meetings are included in Appendix B: Kick-off Meeting (December 5, 2000); First Review Meeting (January 17, 2001); teleconference call on January 30, 2001; Second Review Meeting (February 21, 2001); the teleconference call on March 8, 2001; and the Draft Report Review Meeting (April 12, 2001).

During the Kick-off Meeting(s), WEST met with the U.S. Army Corps of Engineers (the Corps), the North Dakota State Water Commission (NDSWC), the USGS, the North Dakota State Geological Survey (NDSGS), the U.S. Fish and Wildlife Service (USFWS), the U.S. Bureau of Reclamation (USBR), and Dr. Leon Osborne and Dr. Philip J. Gerla at the University of North Dakota. WEST collected data and insight to the various complex processes that occur in the basin. It was decided that the USGS six-box model of Devils Lake would be used instead of HEC-5 to calculate the water surface elevation of Devils Lake (see Section 1.2.2).

WEST presented the preliminary results of the depression delineation and classification efforts for a portion of the Mauvais Coulee subwatershed during the First Review Meeting. The classification process used by WEST to categorize depressions was approved by the meeting participants.

Preliminary HEC-HMS calibration results were discussed during the teleconference call on January 30, 2001. It was decided that the Corps would obtain an outside reviewer to assess WEST's modeling approach and results.

During the Second Review Meeting, WEST presented the results of the HEC-HMS model calibration and associated modeling deficiencies. It was decided that a different modeling approach would be pursued. Depression storage would be modeled as reservoirs in HEC-HMS and the soil moisture accounting units would be used to model the soil storage. WEST undertook development of the PRINET model on a parallel track as a backup to HEC-HMS.

WEST discussed the limitations of the HEC-HMS model and the preliminary results from the PRINET model during the teleconference on March 8, 2001. It was decided that the HEC-HMS modeling efforts would be abandoned and that the PRINET model would be used.

During the Draft Report Review Meeting on April 12, 2001, WEST presented the results of the study and summarized the contents of the Draft Report submitted April 6, 2001. There was some concern that the average annual runoff reduction values were approximately 4 inches, which was significantly less than what was expected based on evaporation rates. WEST agreed to elaborate on the significance of these results in the Final Report. There was a lengthy discussion regarding the terminology used for classifying depressions as “intact” and “drained”. Because field verification was not performed, the modifier “possibly” was added to these classifications. WEST agreed to add a section to the Final Report that presents recommendations for future studies.

## 1.5. ACKNOWLEDGEMENTS

This study was authorized under Contract No. DACW37-00-D-0001, Task Order No. 004, for Hydrologic Engineering Services between the U.S. Army Corps of Engineers, St. Paul District, and WEST Consultants, Inc. (WEST).

Dr. David T. Williams, P.E., as Principal-in-Charge, provided overall guidance and quality assurance. The Project Manager for this work was Mr. Brian J. Doeing, P.E., and Dr. Selena M. Forman, P.E., was the Assistant Project Manager. The following staff members dedicated a great deal of time and effort to ensure the success of this study: Dr. Raymond Walton, P.E.; Mr. Martin J. Teal, P.E.; Mr. A. Jake Gusman, P.E.; Mr. Leo R. Kreymborg, E.I.T.; Dr. Henry Hu, P.E.; Mr. Iwan M. Thomas; Dr. Dragoslav Stefanovic; Mr. Todd Bennett, P.E; Mr. Anand Raman; and Mr. Dan J. Eggers, E.I.T. Mr. Leo R. Kreymborg was the primary PRINET model developer. Ms. Mary R. Dahlke provided clerical assistance.

Polaris Group, Inc., was WEST’s subconsultant for this study. Mr. Richard L. Voigt, Jr., P.E., Mr. Arthur R. Kalmes, P.E., and Mr. Thomas R. Johnson, P.E., provided invaluable assistance collecting data, classifying depressions, participating in brainstorming sessions, providing insight into various aspects of the study, and quality control.

The study manager for the U.S. Army Corps of Engineers, St. Paul District, was Mr. Robert G. Engelstad, P.E.

Also acknowledged are the many representatives of the agencies and organizations who have worked in the Devils Lake basin and have provided valuable information or assistance during the course of this study. The following list includes many of the names of those who provided input or were contacted for information in the course of this study:

Mr. Dave Loss, U.S. Army Corps of Engineers, St. Paul District

Mr. Pat Foley, U.S. Army Corps of Engineers, St. Paul District

Mr. Dan Reinartz, U.S. Army Corps of Engineers, St. Paul District

Dr. Gregg Wiche, U.S. Geological Survey (USGS), Bismarck, ND

Dr. Aldo (Skip) Vecchia, USGS, Bismarck, ND

Dr. Kevin Vining, USGS, Bismarck ND

Mr. Brett Hovde, North Dakota State Water Commission (NDSWC), Bismarck, ND

Mr. Bruce Engelhardt, P.E., NDSWC, Bismarck, ND

Mr. James Landenberger, NDSWC, Bismarck, ND

Mr. Joe Martinetti, NDSWC, Bismarck, ND

Mr. William Pearson, U.S. Fish and Wildlife Service (USFWS), Bismarck, ND

Mr. Allyn J. Sapa, USFWS, Bismarck, ND

Mr. Mike McEnroe, USFWS, Bismarck, ND

Mr. Roger Hollevoet, USFWS, Devils Lake, ND

Mr. Rick Nelson, U.S. Bureau of Reclamation (USBR), Bismarck, ND

Mr. John Bluemle, North Dakota State Geological Survey (NDSGS), Bismarck, ND

Mr. Edward Murphy, NDSGS, Bismarck, ND

Dr. James Arndt, Peterson Environmental Consultants, Inc., Mendota Heights, MN

Dr. Leon Osborne, University of North Dakota, Grand Forks, ND

Mr. R. J. Bowering, P.Eng., Manitoba Conservation and Water Resources, Winnipeg, Manitoba

# 2. DATA COLLECTION

The cooperation of a variety of agencies provided all data required for this hydrologic study of the Devils Lake Upper basin. A brief overview is provided here of the data acquired, how it was used, and how it was produced or provided. Much of this information was in the form of geographic information that was used in conjunction with streamflow, precipitation, and evaporation data to develop a working hydrologic model of the Devils Lake upper basin.

## 2.1. GEOGRAPHIC DATA

ArcView Geographic Information System (GIS), Version 3.2a, developed by the Environmental Systems Research Institute (ESRI), was used in this study to process and analyze the large amounts of geo-based data necessary for hydrologic modeling. Additional software extensions were used in conjunction with ArcView GIS for the hydrologic analysis. The Spatial Analyst and 3D Analyst extensions, which were developed by ESRI, were used in this analysis. These extensions were required to view and process the digital elevation models (DEM's) (the topographic data in a grid format). HEC Geo-HMS, developed in a cooperative effort between ESRI and the Hydrologic Engineering Center (HEC), was used to process GIS data for input to the hydrologic models. The ArcView extension X Tools, created by Mike DeLaune (available at the website: http://gis.esri.com/arcscripts), was also used to perform various tasks within ArcView.

### 2.1.1. Digital Elevation Model

A DEM is a grid that provides elevation data over an area broken down into square grid cells. Each cell has an elevation value considered representative of the area contained by the cell. Digital terrain data for the entire Devils Lake basin was obtained from the USGS and NDSWC. The upper basin subwatersheds (Comstock, Hurricane Lake, Starkweather, Edmore, St. Joe, Calio, and Mauvais Coulee, divided into two subwatersheds, the area upstream of USGS stream gage 05056100 and the remainder of the subwatershed) and associated subbasins and surface depressions were delineated from 10-meter grids obtained from the NDSWC. The local drainage areas for Devils and Stump Lakes were developed from 30-meter grids obtained from the USGS. There was some disagreement in the subwatershed boundaries developed from the 10-meter and 30-meter grids as a result of the different horizontal resolutions. It was assumed that the boundaries developed from the 10-meter grids were correct. The boundaries developed for the Devils Lake and Stump Lake subwatersheds were modified accordingly.

The individual 10-meter grids were merged into one large grid to delineate and characterize the upper basin subwatersheds. The 30-meter grids and bounding 10-meter grids were merged to develop the Devils Lake and Stump Lake subwatersheds. The steps involved in the terrain processing are outlined in subsequent sections.

As shown in Figure 2-1, the USGS quad maps used for the DEM of the upper basin include 61 percent from 1968-1972, 18 percent from 1994, 10 percent from 1957-1958, 6 percent from 1978-1980, and 5 percent from 1962.

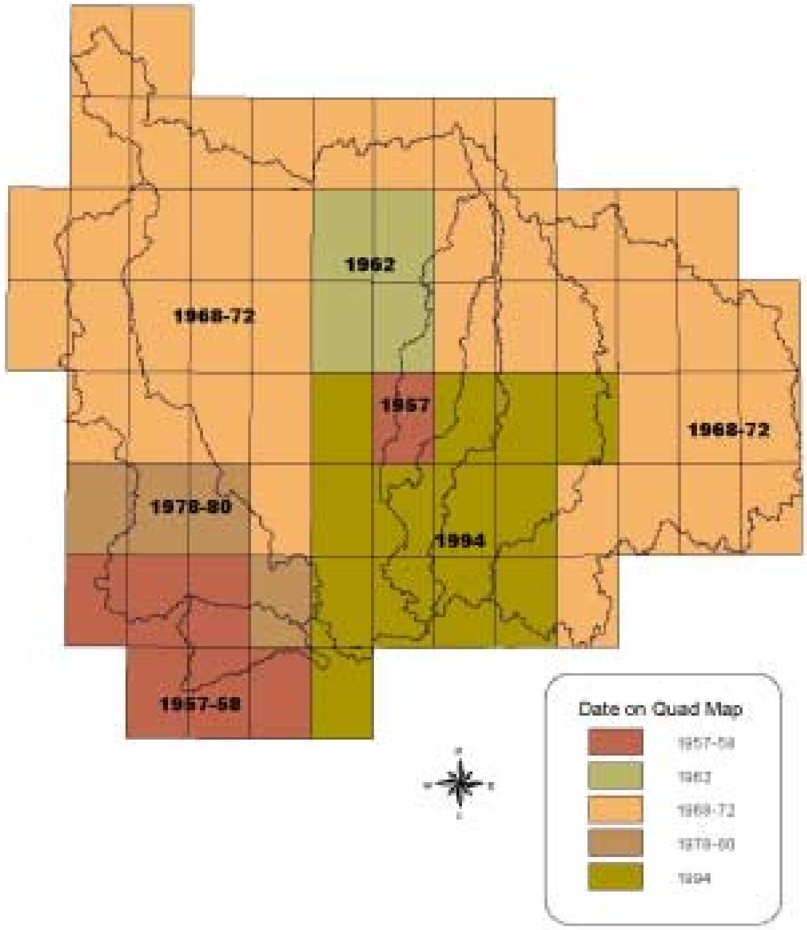



Figure 2-1. USGS quad map dates for Devils Lake upper basin.

The vertical elevations of the DEM grid cells were reported in whole feet for some of these grids and in decimeters for the remainder. Trials using both vertical units showed that the difference in the vertical resolution did not significantly effect the subwatershed delineation or depression volume computations.

The 10-meter DEM's were classified as Level 2, which are elevation data sets that were processed or smoothed for consistency and edited to remove identifiable systematic errors. The DEM record reports the vertical root mean square error (RMSE) statistic to describe the vertical accuracy of the DEM. The RMSE is computed by comparing the linearly interpolated elevations in the DEM with corresponding known elevations. The maximum permitted vertical RMSE for Level 2 DEM's is one-half the contour interval of the parent map. No errors greater than one contour interval are allowed.

The majority of the DEM's for the upper basin were based on 5-foot contour interval data, as shown in Figure 2-2 (1,708 $mi^2$ 5-foot contour area compared to 2,616 $mi^2$ total area). However, the DEM's on the west side of the upper basin (Comstock, Hurricane Lake, and part of the

Mauvais Coulee subwatersheds) were based on 10-foot contour interval data. The reported vertical RMSE's for the DEM's from the 5-foot contour interval were less than or equal to 2 feet. For the DEM's derived from 10-foot contour interval data, the reported vertical RMSE's were three feet.

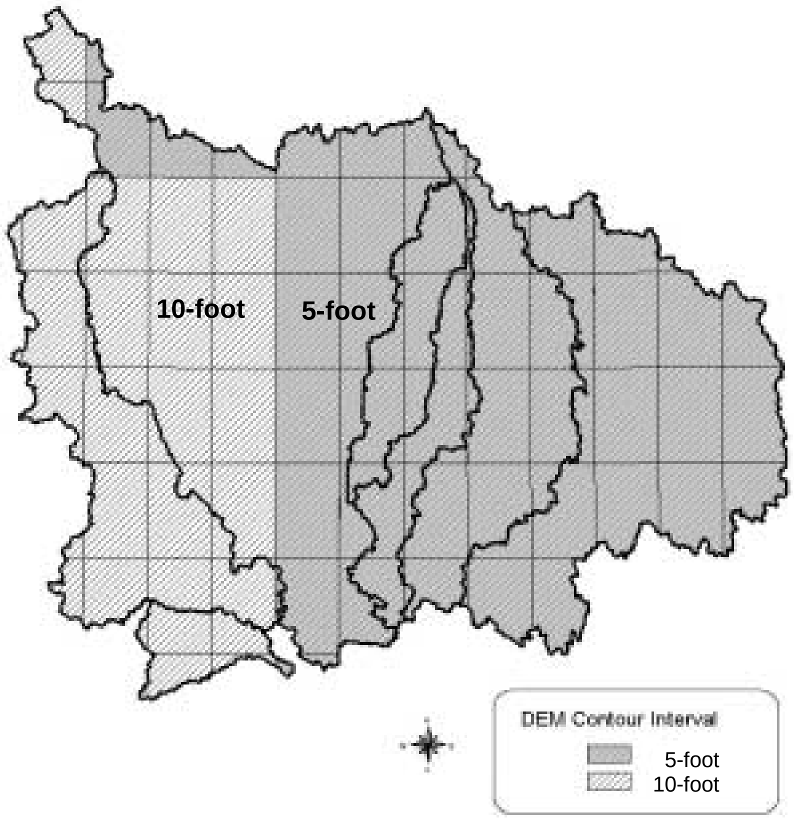



Figure 2-2. DEM contour interval for Devils Lake upper basin.

The contour interval of the parent map used to generate the cell elevation values for the DEM had a significant effect on the amount of depressions recognized by ArcView. The majority of the DEM of the upper basin was based on 5-foot contour interval data. However, on the western side of the upper basin (the area covering Comstock, Hurricane Lake, and the most western portions of Mauvais Coulee) elevation values for the grid cells were generated from 10-foot contour interval data. In the area covered with 5-foot contour interval data most of the depressions were captured by the DEM. In the portion of the basin where elevation values were generated from 10-foot contour data, many small depressions were not represented in the DEM. Techniques used to overcome this low resolution are discussed in Section 3.

### 2.1.2. <u>Hydrologic Processing</u>

HEC-GeoHMS was used to process the DEM and create a set of three grids used in the analysis of the subwatersheds, a hydrologically corrected grid (filled grid), a flow direction grid, and a flow accumulation grid (Hydrologic Engineering Center, 2000). The hydrologically corrected, or “filled” grid, is generated by filling small depressions (i.e., sinks) in the original DEM. The elevation of each grid cell is compared to its eight neighboring cells. If the elevation of the middle cell is lower than all of the surrounding cells, the elevation of that middle cell is increased to the elevation value of the lowest neighboring cell. Once the filled grid is created, the flow direction is calculated for each cell by comparing the slope from a grid cell to each of the neighboring eight cells. The water flows in the direction of the steepest downward slope. After the flow direction for each cell has been determined, the flow accumulation grid is created. The number of upstream cells draining into a given cell is computed and stored in the flow accumulation grid. The drainage area to any cell can be computed from the flow accumulation grid.

### 2.1.3. Digital Orthographic Quads

Digital Orthographic Quads (DOQ’s), black and white aerial photographs covering the 7.5 minute quadrangles of the entire study area, were provided by the Corps. These DOQ’s were geo-referenced so that they would overlay the other GIS data. These photos were used to classify depressions and confirm drainage paths and patterns throughout the study area (see Section 3).

### 2.1.4. USGS Digital Quadrangle Maps

Digital Quadrangle Maps (Quad Maps), provided by the NDSWC, were used to supplement the data provided by the DOQ’s when classifying depressions and drainage patterns. These quad maps provided assistance particularly when identifying bodies of water. Streams that appear on the quad maps also provided insight into identifying drainage patterns when classifying depressions (see Section 3).

### 2.1.5. National Wetlands Inventory Data

The U.S. Fish and Wildlife Service provided its National Wetlands Inventory (NWI) data in GIS format. The NWI classification system (Cowardin et al., 1979) is hierarchical, with wetland and deepwater habitats divided among five major systems at the broadest level. Systems are further subdivided into subsystems that reflect hydrologic conditions. Below the subsystem is the class that describes the appearance of the wetland in terms of vegetation or substrate. Each class is further subdivided into subclasses; vegetated subclasses are described in terms of life form and substrate subclasses in terms of composition. The classification system also includes modifiers to describe hydrology (water regime), soils, water chemistry, and special modifiers relating to human or animal activity (e.g., partly drained, excavated, beaver, etc.). The NWI wetland delineation and digital data are based on high altitude color infrared aerial photography from 1979 and 1983. These data were used to supplement those depressions delineated by ArcView as described in Section 3.2.

The NWI delineations include only those wetlands that meet the NWI wetland definition. The NWI data do not include wetlands that were completely drained prior to 1979.

### 2.1.6. <u>Soil Types</u>

The North Dakota State Geologic Survey provided GIS data characterizing soil types for most of the upper basin (see Figure 2-3). Soil survey data was not available for Pierce and Benson counties, which correspond to the Comstock subwatershed and part of the Hurricane Lake and Mauvais Coulee subwatersheds. The primary soil types in the upper basin watershed were the Barnes-Buse loams, the Hamerly-Tonka-Parnell complexes, the Hamerly-Barnes loams and the Vallers-Saline Parnell complexes. The reported range of infiltration rates for these soils were the same: 0.06 to 2 inches per hour. The different soil types were randomly dispersed throughout the study area, without an obvious pattern. The relationship between the soil types and depressions is discussed in Section 3.

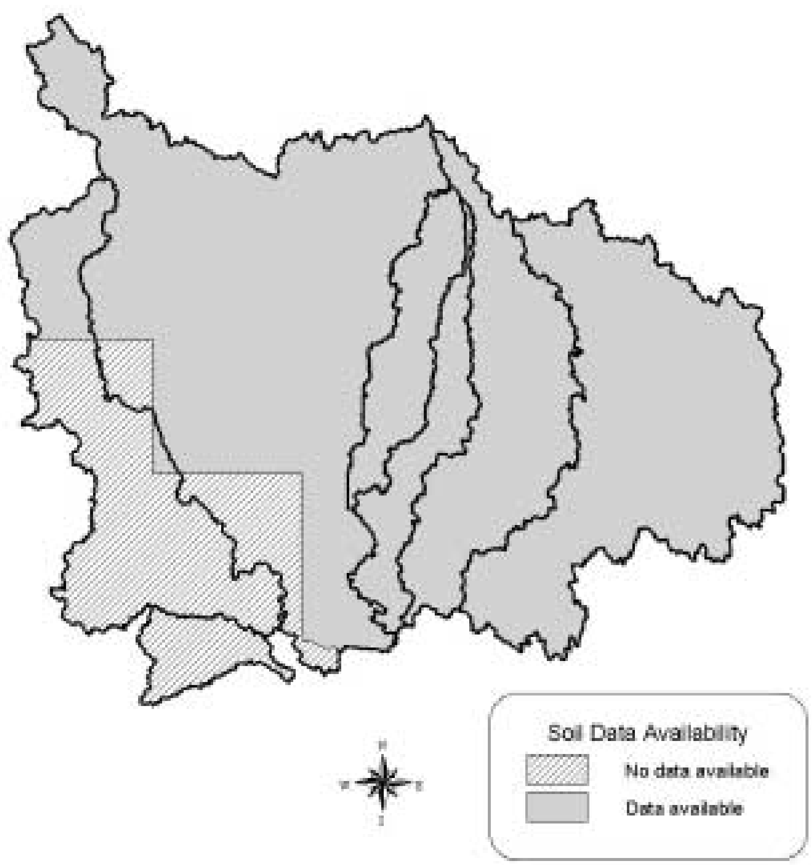



Figure 2-3. Availability of soil survey data for the Devils Lake upper basin.

Hydric soil types found in the Devils Lake upper basin are listed in Table 2-1. Soil complexes containing one or more of these soils were considered hydric. The surface area percentage of hydric soils in each subwatershed is provided in Table 2-2.

Table 2-1. Hydric soils in the Devils Lake upper basin.

| | | |
|---|---|---|
| Arveson | Lallie | Roliss |
| Borup | Lamoure | Ryan |
| Colvin | Lindaas | Southam |
| Fargo | Ludden | Stirum |
| Fossum | Marysland | Tiffany |
| Hamar | Parnell | Tonka |
| Hegne | Rauville | Vallers |

Table 2-2. Hydric soils by subwatershed.

| **Subwatershed** | **Area with Hydric Soils** (as percent of area with soils coverage) | **Area with Non-hydric Soils** (as percent of area with soils coverage) | **Soils Data Availability** (as percent of total subwatershed area) |
|---|---|---|---|
| Calio Coulee | 41% | 59% | 100% |
| Comstock | n/a | n/a | 0% |
| Edmore Coulee | 32% | 68% | 100% |
| Hurricane Lake | 19% | 81% | 23% |
| Mauvais Coulee | 36% | 64% | 82% |
| St. Joe Coulee | 31% | 69% | 100% |
| Starkweather Coulee | 33% | 67% | 100% |

## 2.2. PRECIPITATION AND SNOWMELT DATA

### 2.2.1. Precipitation Data

Fifty-three (53) precipitation gages were identified in the Devils Lake region from the National Climatic Data Center (NCDC), the North Dakota "Handbook 5" list available from the National Weather Service web page, and local sources. Data were available for 21 of these gages. Unfortunately, some of these gage records had incomplete records for the main study period (1980-1999).

Fourteen gages in the Devils Lake region had complete records in the study period. Six of these gages, which were within or near the Devils Lake upper basin watershed, were used for this study (see Figure 2-4). The precipitation gages were assigned to the individual subbasins within the subwatersheds based primarily, but not entirely, on proximity (see Section 5). These gages are described in Table 2-3. The annual precipitation values for the upper basin gages are provided in Table 2-4.

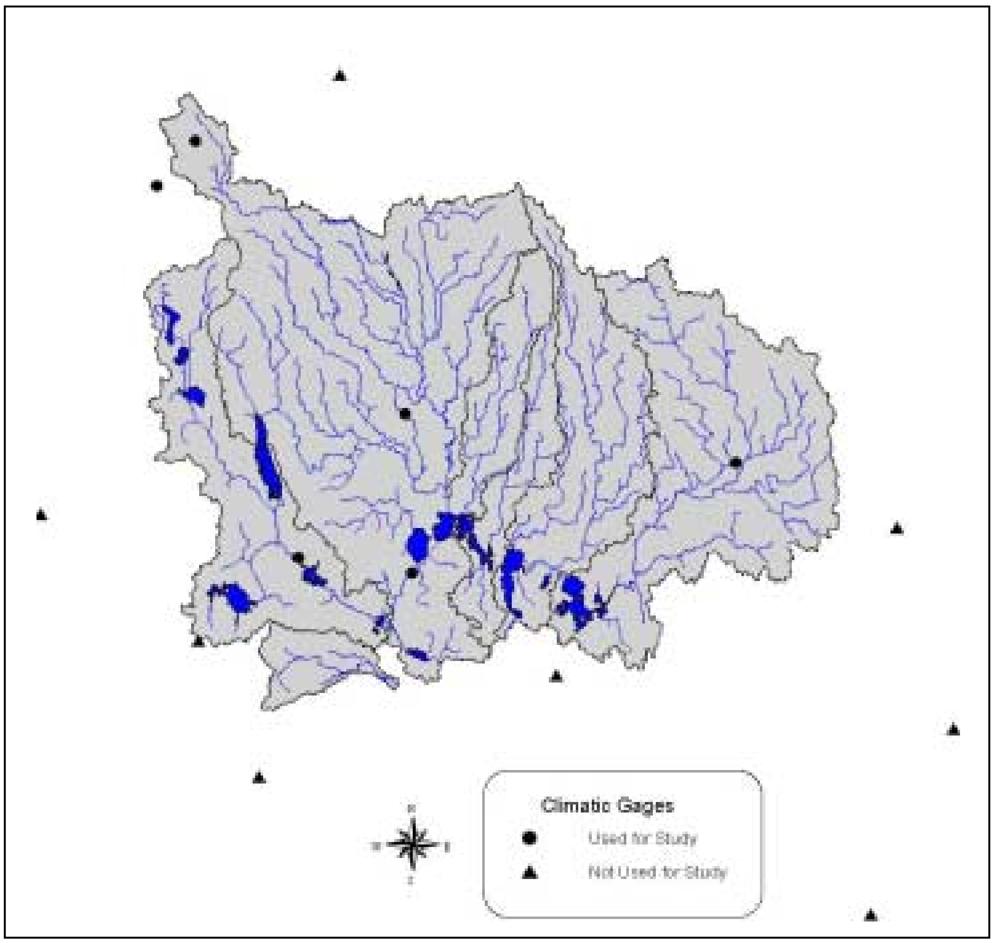



Figure 2-4. Climatic gages in the Devils Lake region with complete records in the study period.

Table 2-3. Summary of precipitation data used in the Devils Lake study area.

| Gage Id. | Location | Period-of-Record | Data Source | Temperature Data |
|---|---|---|---|---|
| BCTN8 | Belcourt | 1/1/48 to 1/7/01 | NCDC | Yes |
| CAON8 | Cando | 1/1/50 to 1/7/01 | NCDC | Before 5/12/94, used temperature from Church's Ferry. After 5/23/94, used temperature data from a different Cando gage, Cando 2SE. |
| CFYN8 | Church's Ferry | 1/1/76 to 1/7/01 | NCDC | Reported temperature data was interpolated from surrounding gaging stations. |
| EDRN8 | Edmore | 1/1/48 to 1/3/01 | NCDC | Yes |
| LDSN8 | Leeds | 1/1/48 to 1/2/01 | NCDC | Yes |
| RLAN8 | Rolla | 1/1/48 to 1/3/01 | NCDC | Yes |

Table 2-4. Annual precipitation at upper basin precipitation gages.

| WATER YEAR | ANNUAL PRECIPITATION (IN) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Belcourt** | **Cando** | **Church's Ferry** | **Edmore** | **Leeds** | **Rolla** | **Average** |
| 1979 | 14.6 | 16.3 | 14.0 | 13.8 | 20.4 | 16.3 | 15.9 |
| 1980 | 21.2 | 19.2 | 16.2 | 17.5 | 19.4 | 21.0 | 19.1 |
| 1981 | 16.8 | 18.2 | 16.3 | 18.7 | 17.1 | 19.3 | 17.7 |
| 1982 | 24.2 | 19.5 | 17.8 | 18.4 | 21.2 | 21.0 | 20.4 |
| 1983 | 15.9 | 18.8 | 15.9 | 20.1 | 17.6 | 17.1 | 17.6 |
| 1984 | 13.8 | 13.7 | 11.7 | 11.3 | 16.6 | 14.2 | 13.5 |
| 1985 | 16.6 | 19.0 | 16.7 | 18.5 | 18.5 | 19.0 | 18.0 |
| 1986 | 21.3 | 16.8 | 17.4 | 21.6 | 21.2 | 21.0 | 19.9 |
| 1987 | 20.0 | 17.7 | 15.0 | 16.9 | 17.9 | 18.9 | 17.7 |
| 1988 | 9.8 | 8.9 | 7.3 | 8.0 | 9.4 | 9.8 | 8.9 |
| 1989 | 16.2 | 11.0 | 10.0 | 11.5 | 14.2 | 15.4 | 13.0 |
| 1990 | 16.5 | 12.9 | 10.7 | 12.5 | 12.8 | 16.3 | 13.6 |
| 1991 | 25.6 | 20.6 | 18.1 | 21.9 | 20.2 | 24.4 | 21.8 |
| 1992 | 12.6 | 12.3 | 9.6 | 14.6 | 14.8 | 14.6 | 13.1 |
| 1993 | 26.5 | 22.7 | 23.0 | 33.8 | 26.3 | 25.8 | 26.4 |
| 1994 | 16.6 | 14.6 | 15.9 | 17.5 | 19.0 | 15.1 | 16.5 |
| 1995 | 23.7 | 17.5 | 17.3 | 20.2 | 22.7 | 21.3 | 20.4 |
| 1996 | 16.2 | 24.4 | 16.3 | 24.1 | 18.1 | 18.4 | 19.6 |
| 1997 | 21.3 | 21.1 | 13.9 | 23.8 | 17.3 | 17.5 | 19.2 |
| 1998 | 24.5 | 19.0 | 18.7 | 22.3 | 17.2 | 21.1 | 20.5 |
| 1999 | 24.0 | 22.1 | 23.3 | 28.3 | 27.6 | 22.7 | 24.7 |
| 2000 | 20.4 | 18.6 | 20.8 | 17.5 | 21.3 | 18.3 | 19.5 |
| Total ('79-'00) | 418.4 | 384.9 | 346.0 | 412.7 | 410.7 | 408.6 | 396.9 |
| Vs. Average | 105% | 97% | 87% | 104% | 103% | 103% | -- |

### 2.2.2. Snowmelt Modeling

The degree-day method used in the HEC-1 rainfall/runoff model was selected for simulating snowmelt runoff. HEC-1 is the U.S. Army Corps of Engineers Flood Hydrograph Package (Hydrologic Engineering Center, 1990). The degree-day method required precipitation and temperature inputs for the snowmelt calculations. Another option investigated was the energy budget method, which required this same data plus solar radiation, wind speed and dew point temperature. The available data (both spatial and temporal) was not sufficient to effectively use the energy budget snowmelt method for all of the gages in the Devils Lake basin. Furthermore, preliminary trials at the Cando gage showed that the computed snowmelt from the energy budget method was not significantly different than the snowmelt produced from the degree-day method. The snowmelt algorithm is described in Section 4 and Appendix A.

## 2.3. STREAMFLOW DATA

Ten (10) streamflow gaging stations with daily streamflow measurements were identified in the Devils Lake upper basin (see Figure 2-5 and Table 2-5). Data were obtained for these stations from the USGS. Several of the gages have very short periods-of-record and many operate only during March through September. Because there is typically very little or no flow during winter months, the missing streamflows did not impact the study. These gages contained sufficient information for calibration of each of the subwatersheds in the Devils Lake hydrologic model. Data from these gages were processed using the HEC Data Storage System (HEC-DSS) and Microsoft Access.

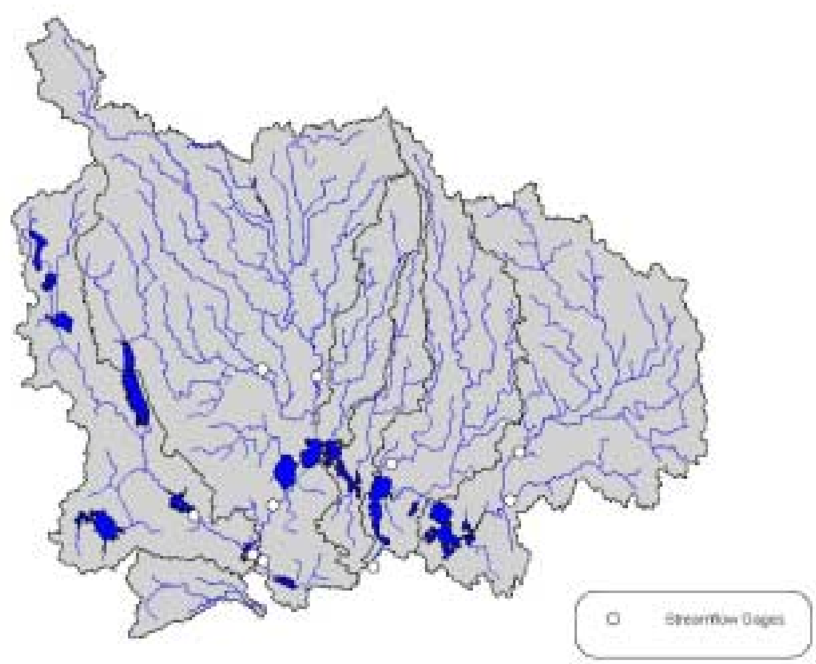



Figure 2-5. Streamflow gaging stations in the Devils Lake upper basin.

Table 2-5. Summary of streamflow gages used in the Devils Lake study area.

| Gage No. | Gage Name | Period-of-Record | Comments |
|---|---|---|---|
| 05056060 | Mauvais Coulee Trib. #3 | 3/1/86 to 9/30/99 | Mar-Sep records for all years except 1987 and 1988. Winter data available: 1992, 1994 only. |
| 05056100 | Mauvais Coulee Nr Cando | 6/1/56 to 10/31/00 | Oct-Feb data missing for most water years. |
| 05056200 | Edmore Coulee Nr Edmore | 7/1/57 to 10/31/00 | Mar-Sep data for all years. Oct-Feb data in 1958-1982 and 1993-1994. |
| 05056215 | Edmore Coulee Trib Nr Webster | 3/1/86 to 9/30/99 | Mar-Sep data for all years. Oct-Feb data in 1993-1994. |
| 05056239 | Starkweather Coulee Nr Webster | 10/1/79 to 9/30/99 | Mar-Sep data for all years. Oct-Feb data in 1979-1986 and 1993-1994. |
| 05056270 | Big Coulee Bl Church's Ferry | 3/1/98 to 9/30/99 | |
| 05056340 | Little Coulee Nr Leeds | 3/1/98 to 9/30/99 | |
| 05056390 | Little Coulee Nr Brinsmade | 8/27/75 to 9/30/97 | Mar-Sep data for all years. Oct-Feb data in 1979-1982 and 1993-1994. |
| 05056400 | Big Coulee Nr Church's Ferry | 10/1/50 to 9/30/97 | |
| 05056410 | Channel A Nr Penn | 10/1/83 to 9/30/99 | |

## 2.4. DEVILS LAKE EVAPORATION

The USGS provided monthly evaporation values for Devils Lake from 1980 through 1999 (see Table 2-6). Since the hydrologic model uses daily time steps, the monthly evaporation values were converted to daily values. The daily Devils Lake evaporation values were computed by converting the monthly Devils Lake evaporation data to daily values using the pattern observed at the Langdon pan evaporation gage. Evaporation data from the Langdon gage was provided by the High Plains Climate Center.

Table 2-6. Monthly evaporation data for Devils Lake (inches).

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1980 | 0 | 0 | 0 | 0.45 | 4.18 | 6.10 | 7.05 | 5.34 | 3.70 | 2.18 | 1.58 | 0 |
| 1981 | 0 | 0 | 0 | 2.10 | 3.50 | 4.55 | 5.66 | 6.03 | 4.86 | 1.43 | 1.04 | 0 |
| 1982 | 0 | 0 | 0 | 0.45 | 2.86 | 4.64 | 5.23 | 5.93 | 4.79 | 1.41 | 1.02 | 0 |
| 1983 | 0 | 0 | 0 | 0.45 | 3.59 | 5.09 | 5.50 | 6.41 | 5.70 | 1.68 | 1.21 | 0 |
| 1984 | 0 | 0 | 0 | 1.37 | 3.87 | 4.45 | 6.06 | 6.67 | 5.34 | 1.58 | 1.14 | 0 |
| 1985 | 0 | 0 | 0 | 1.42 | 4.03 | 5.92 | 6.21 | 5.61 | 4.48 | 1.32 | 0.95 | 0 |
| 1986 | 0 | 0 | 0 | 2.68 | 3.51 | 7.19 | 4.72 | 6.21 | 3.76 | 1.11 | 1.74 | 0 |
| 1987 | 0 | 0 | 0 | 1.31 | 3.63 | 7.28 | 4.92 | 6.09 | 4.32 | 3.82 | 1.84 | 0 |
| 1988 | 0 | 0 | 0 | 1.44 | 4.12 | 8.81 | 6.78 | 6.63 | 4.61 | 4.08 | 1.97 | 0 |
| 1989 | 0 | 0 | 0 | 1.33 | 3.72 | 5.08 | 6.90 | 6.94 | 5.24 | 4.64 | 2.24 | 0 |
| 1990 | 0 | 0 | 0 | 1.36 | 3.81 | 5.44 | 5.82 | 6.76 | 5.89 | 5.21 | 2.51 | 0 |
| 1991 | 0 | 0 | 0 | 1.51 | 4.39 | 4.97 | 5.87 | 6.97 | 4.95 | 4.38 | 1.06 | 0 |
| 1992 | 0 | 0 | 0 | 1.37 | 3.86 | 5.66 | 3.98 | 5.26 | 4.41 | 3.90 | 0.94 | 0 |
| 1993 | 0 | 0 | 0 | 1.26 | 3.44 | 4.31 | 3.43 | 4.49 | 3.92 | 3.47 | 0.84 | 0 |
| 1994 | 0 | 0 | 0 | 1.34 | 3.75 | 4.55 | 4.88 | 5.64 | 4.73 | 2.79 | 0.67 | 0 |
| 1995 | 0 | 0 | 0 | 2.11 | 4.58 | 5.16 | 6.25 | 6.21 | 5.08 | 2.99 | 0.72 | 0 |
| 1996 | 0 | 0 | 0 | 0.45 | 2.70 | 5.08 | 5.02 | 6.12 | 4.55 | 2.69 | 0.65 | 0 |
| 1997 | 0 | 0 | 0 | 0.45 | 3.52 | 7.02 | 4.75 | 5.65 | 5.02 | 2.96 | 0.71 | 0 |
| 1998 | 0 | 0 | 0 | 2.08 | 3.46 | 4.00 | 5.60 | 6.05 | 5.56 | 3.28 | 0.79 | 0 |
| 1999 | 0 | 0 | 0 | 0.45 | 3.14 | 4.42 | 4.91 | 5.56 | 5.59 | 3.30 | 0.79 | 0 |

# 3. DEPRESSION DELINEATION AND CLASSIFICATION

Depressions were delineated and classified for the entire upper basin watershed. First, the digital elevation model (DEM) was processed using HEC-GeoHMS to determine the location, area, and volume of depressions in the upper basin subwatersheds. Second, using the flow chart in Figure 3-1, the depressions were categorized as *possibly intact*, *possibly drained*, *lake*, or *other* based on aerial photos, National Wetlands Inventory (NWI) data, flow direction data, and digital quad maps. Next, the depressions not captured by the DEM were added and classified based on the aerial photos and NWI data. The average depth (and volume) for each of the non-DEM depressions was estimated based on an average depth-area relationship developed from all of the DEM-derived depressions. Finally, a comprehensive quality assurance review of the classified depressions was conducted for the entire upper basin. Each of these steps is described in detail below. The depression totals for possibly intact and possibly drained depressions, comparisons to previous studies of upper basin storage, and the limitations and advantages of the current study's delineation/classification process are discussed.

The depressions described as "possibly drained" in this report may be fully drained, mostly drained, partially drained, likely drained (i.e., appears drained, but not definitively so), filled-in, or otherwise non-intact or non-functional. The clear presence of a man-made drain was not a prerequisite for classifying a depression as "possibly drained". In a similar manner, depressions labeled as "possibly intact" could be fully intact, mostly intact, or likely intact (i.e., appears intact, but not definitively so). The presence of standing water was not a prerequisite for classifying a depression as "possibly intact" because water in a shallow depression could be fully lost to evaporation.

## 3.1. DEM-DERIVED DEPRESSION DELINEATION

The HEC-GeoHMS extension was used within ArcView GIS to create the depression grid from the digital elevation model (DEM). The USGS quad maps used for the DEM of the upper basin include 61 percent from 1968-1972, 18 percent from 1994, 10 percent from 1957-1958, 6 percent from 1978-1980, and 5 percent from 1962 (see Figure 2-1). In creating the depression grid, first the HEC-GeoHMS Terrain Preprocessing function *Fill Sinks* was used to "fill" all of the depressions in the DEM grid, producing a depressionless grid of the Devils Lake upper basin. This filling is accomplished by increasing the elevation of the depression grid cells to the pour point of each depression. Typically, the pour point was defined as the point on each depression with the maximum flow accumulation. This pour point represents the elevation at which water spills out of the depression.

The original DEM grid was subtracted from the filled, depressionless grid, creating a new grid with only the depths in all of the depressions. Next, this depression grid was converted into a polygon theme, and ArcView was also used to calculate the surface area, volume, and average depth (volume/area) for each depression polygon. Finally, the DEM-derived depressions were classified using the method described in Section 3.3.

### 3.2. <u>NON-DEM DEPRESSIONS</u>

The original DEM grid was based on 5-foot contour interval data for a majority of the upper basin. In this area, most of the depressions were captured by the DEM. However, on the west side of the upper basin (i.e., Comstock, Hurricane Lake, and a portion of the Mauvais Coulee subwatersheds), the DEM is based on 10-foot contour interval data, as shown in Figure 2-2. The larger contour interval in this area limited the capture of depressions by the DEM.

Since some depressions were not delineated by the DEM in this area, the DEM-derived depressions were supplemented by polygons based on the NWI and aerial photos. NWI polygons that did not overlap the DEM-derived depressions were added to the depression theme. For the sake of consistency throughout the watershed, non-overlapping NWI polygons were added to the entire upper basin, including both the 5-foot and 10-foot contour interval areas. It should be noted that the NWI wetland definition and the resulting NWI polygons do *not* include depressions that were completely drained prior to 1979. Therefore, any completely drained depressions not captured by the DEM nor by the NWI data are not incorporated into the data set.

In addition to the NWI polygons, a relatively small number of depression polygons (<900) were added manually based on the aerial photos. In most of these cases, a clearly intact depression was represented by a DEM-derived polygon that was much smaller than the corresponding depression. A more accurate polygon was digitized, and the small DEM-derived polygon deleted from the depression theme. A summary of depression totals versus depression source (DEM and non-DEM) is provided in Table 3-1 below. Depression totals versus depression source are provided by subwatershed in Table 3-2. Depression totals grouped by depression type (possibly intact or possibly drained) are given in Section 3.4.

Table 3-1. DEM and non-DEM depressions in the Devils Lake upper basin.

| **Depression Source** | **Count** | **Area** (acres) | **Volume** (acre-ft) |
|---|---|---|---|
| DEM | 39,723 | 252,310 | 567,303 |
| Non-DEM: | | | |
| Added from National Wetlands Inventory | 75,117 | 35,242 | 29,028 |
| Added manually based on aerial photos | 828 | 6,867 | 18,002 |
| Total | 115,668 | 294,419 | 614,333 |

Table 3-2. DEM and non-DEM depressions by subwatershed.

| Subwatershed | Depression Source | Count | Area (acres) | Volume (acre-ft) |
|---|---|---|---|---|
| Calio Coulee | DEM | 2,036 | 14,518 | 27,133 |
| | Non-DEM | 1,909 | 1,141 | 959 |
| Comstock | DEM | 943 | 4,352 | 11,711 |
| | Non-DEM | 2,312 | 1,206 | 1,049 |
| Edmore Coulee | DEM | 12,207 | 77,314 | 168,409 |
| | Non-DEM | 4,262 | 3,313 | 3,161 |
| Hurricane Lake | DEM | 3,283 | 18,017 | 58,541 |
| | Non-DEM | 18,024 | 11,563 | 19,975 |
| Mauvais Coulee | DEM | 13,740 | 85,876 | 193,026 |
| | Non-DEM | 45,323 | 21,979 | 19,494 |
| St. Joe Coulee | DEM | 1,930 | 13,322 | 22,943 |
| | Non-DEM | 1,747 | 1,134 | 917 |
| Starkweather Coulee | DEM | 5,584 | 38,912 | 85,540 |
| | Non-DEM | 2,368 | 1,773 | 1,475 |

All of the non-DEM depressions were classified in the same manner as the DEM-derived depressions (see Section 3.3). The average depth and volume of the non-DEM polygons – those added manually or supplemented from NWI – were approximated based on a depth-area regression relationship derived from DEM depressions in the entire upper basin (see Appendix C).

A combination of the 10-foot contour interval and the HEC-GeoHMS grid processing algorithms resulted in an artificially large depression in the northwest portion of the Hurricane Lake subwatershed (confirmed by the aerial photos). NWI and manually added polygons were used in this area instead of the single, large depression.

In addition to the classification process, the subwatershed, county, and quadrangle containing each depression was identified. If a depression polygon intersected a subwatershed boundary (or a county or quadrangle boundary), the polygon was assigned to the subwatershed (or county or quadrangle) containing the center of the polygon. Each depression polygon was also assigned a unique polygon ID number.

## 3.3. <u>DEPRESSION CLASSIFICATION</u>

### 3.3.1. <u>Classification Categories</u>

Four categories were used in classifying the depressions:

- **Possibly intact** – includes depressions that may be fully intact, mostly intact, or likely intact (i.e., appears intact, but not definitively so). The presence of standing water was not a prerequisite for classifying a depression as "possibly intact" because water in a shallow depression could be fully lost to evaporation.

- **Possibly drained** – includes depressions that may be fully drained, mostly drained, partially drained, likely drained (i.e., appears drained, but not definitively so), filled-in, or otherwise non-intact or non-functional. The clear presence of a man-made drain was not a prerequisite for classifying a depression as "possibly drained".

- **Lake** – includes named lakes shown on USGS digital quadrangle map.

- **Other** – includes depressions representing drainage ways, and depression polygons now overlapping highways, houses, etc.

Based upon the available data and classification procedure, the depressions were classified as either “intact” or “drained” (in addition to “lake” and “other”). However, because field verification was not performed, the modifier “possibly” was added to the “intact” and “drained” categories.

### 3.3.2. <u>Classification Data and Flow Chart</u>

The depression classification process was based on the following data:

- Aerial photos (digital orthoquads, Oct. 1997)

- National Wetlands Inventory (NWI) data

- USGS digital quad maps

- Flow direction data (from HEC-GeoHMS)

Paper prints of color infrared photography (CIR) from June 1997 were available. However, the color infrared photography was not available in digital format. Since the delineated depressions and the classification data (aerial photos, NWI data, USGS quad maps, and flow direction data) were all used in digital format, the use of the CIR paper prints was not feasible for this study. A flow chart detailing the depression classification process was developed (see Figure 3-1). The purpose of the flow chart was to ensure that a consistent procedure was used by the different scientists and engineers conducting the classification. The use of this flow chart was presented and approved at the project’s First Review Meeting (January 17, 2001), which was attended by representatives of the Corps of Engineers, N.D. State Water Commission, U.S. Fish and Wildlife Service, and the U.S. Geological Survey.

### 3.3.3. Soil Survey Data (Hydric Soil Delineations)

Soil survey data were initially considered for use in the delineation and classification processes. Certified Soil Survey Geographic (SSURGO) data for Cavalier, Rolette and Towner counties, as well as uncertified SSURGO data for Ramsey and Walsh counties, were analyzed. The delineated depressions (DEM and non-DEM), as well as the original NWI coverage, were compared to the hydric/non-hydric soil delineations within the Mauvais 6100 subarea.

The analysis showed that the majority of surface area for both the original NWI polygons and the delineated depressions were found within hydric soil areas. Approximately 78 percent (14,305 acres) of the NWI polygon surface area overlapped hydric soils. For the DEM and non-DEM depressions used in this study, 68 percent (29,466 acres) of the surface area overlapped hydric soils.

While depressions were more likely to be located within hydric soil areas, the hydric soil delineations covered a much greater surface area than either the classified depressions or the original NWI polygons, as shown in Figure 3-2 (a) and (b). In the Mauvais Gage 6100 subarea, hydric soils make up 87,634 acres, or 42 percent of the total watershed area. Overlaying the hydric soil delineations on aerial photos confirmed that these delineations usually encompassed too large an area to be useful in delineating individual depressions, as illustrated in Figure 3-2 (c).

Other reasons why the soil survey data were not used in delineating or classifying depressions include:

- Small hydric soil "inclusions" found within the non-hydric soils are not represented in the soil survey data. Likewise, small non-hydric soil "inclusions" found within the hydric soils are not represented.

- A significant portion (32 percent) of the classified depression area in Mauvais 6100 did not overlap hydric soils. However, the presence of a depression was confirmed by the aerial photos. Figure 3-2 (c) illustrates some of the depressions that do not correspond to hydric soil areas.

- Soil survey data were not available for Pierce and Benson counties, which primarily correspond to the 10-foot contour interval area where the addition of depression area using soil types would be the most useful (see Figure 2-3 in Section 2). As a result, no soil data were available for about 50 percent of the 10-foot contour area.

While the hydric soil delineations were not used in this study, a more refined hydric soils coverage may be useful in estimating the depression surface area missed by both the DEM grid and NWI polygons.

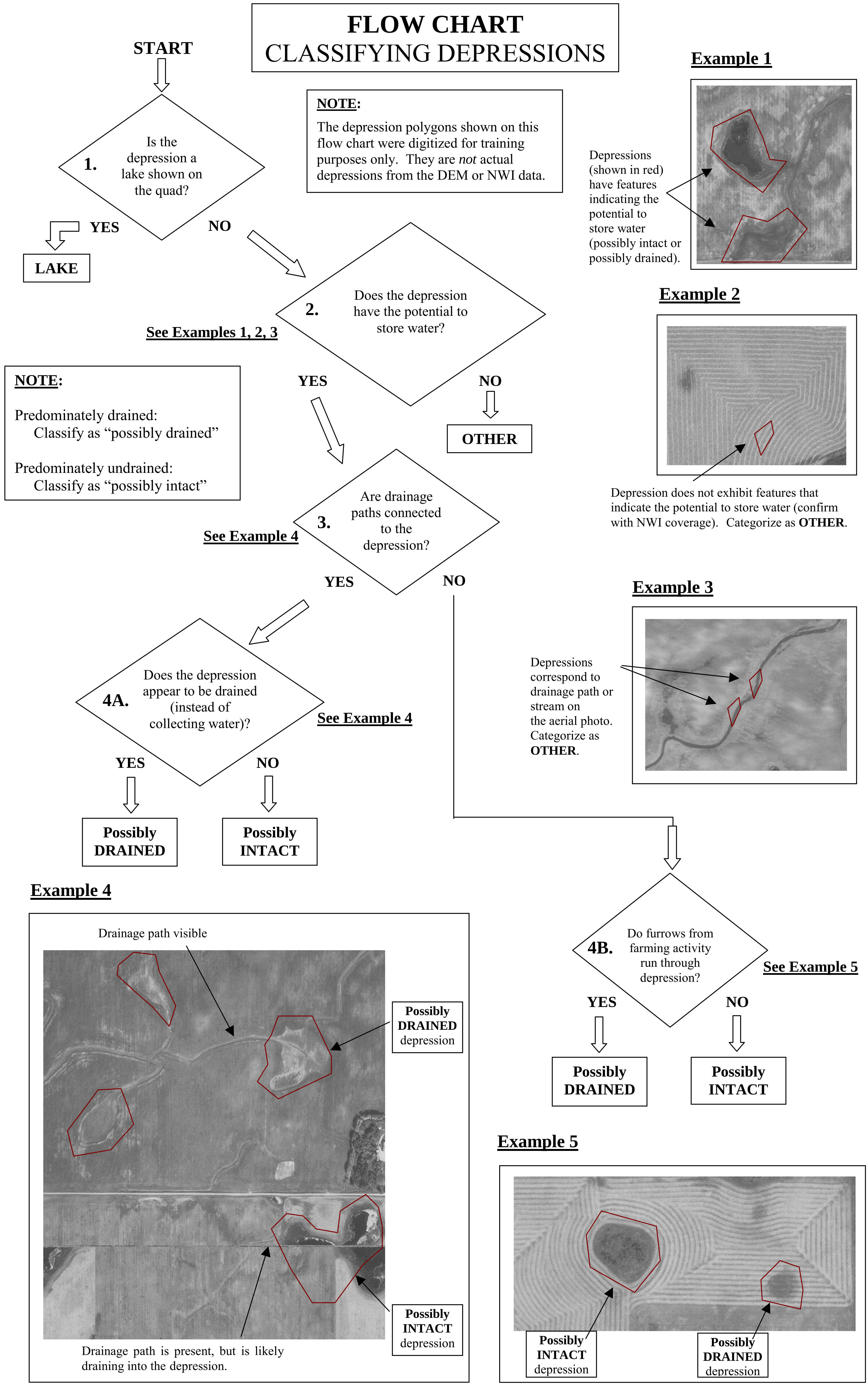
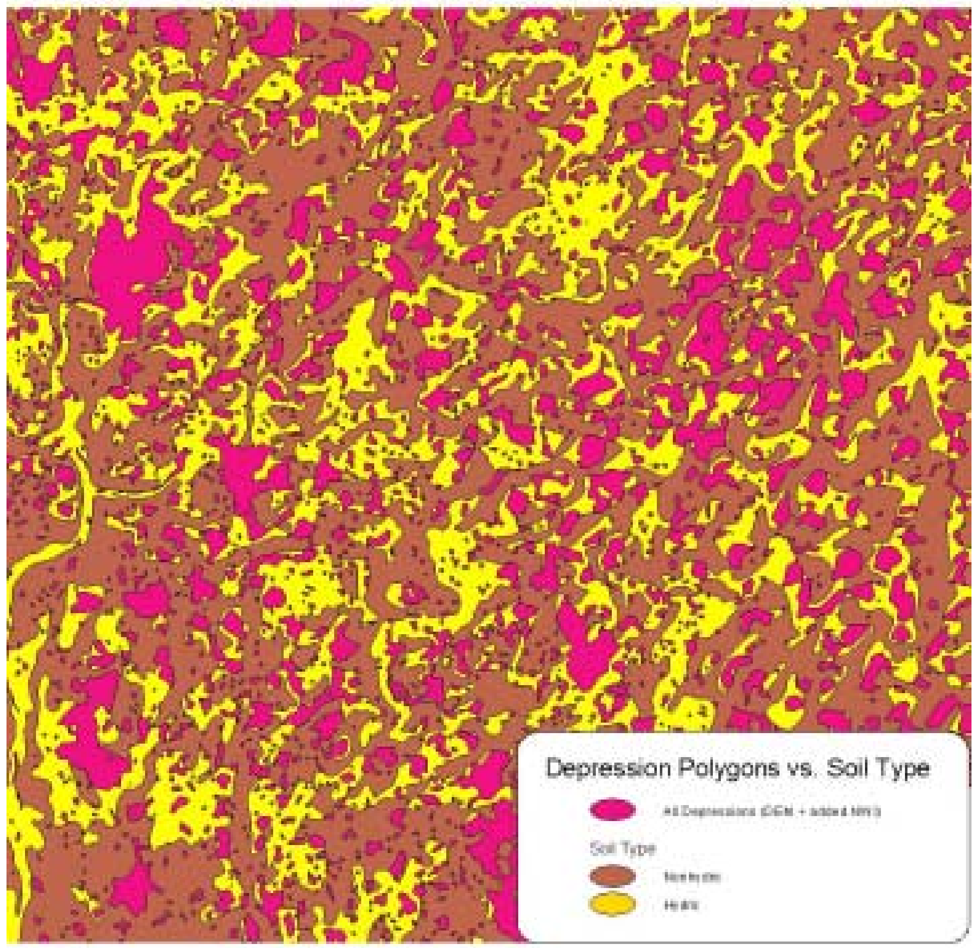
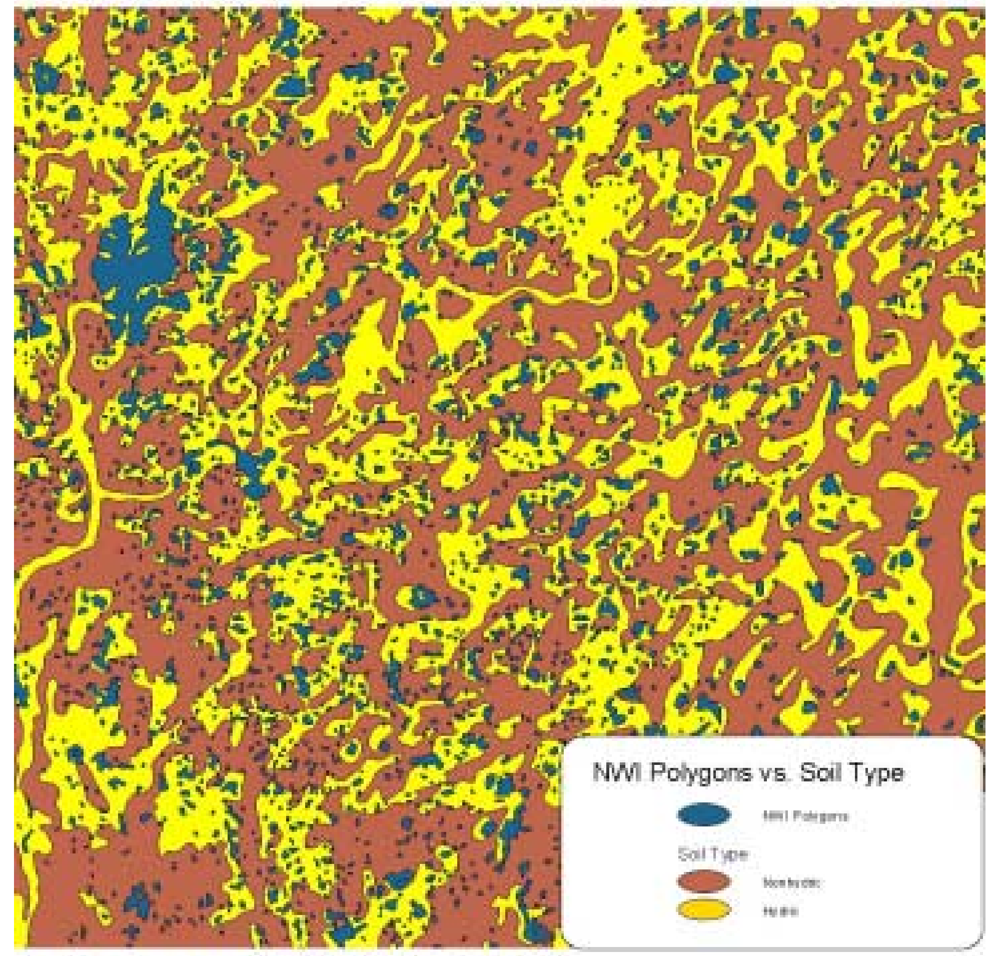



Figure 3-1. Flow chart – Classifying depressions

**(a) Depression polygons versus soil type (hydric/non-hydric)**

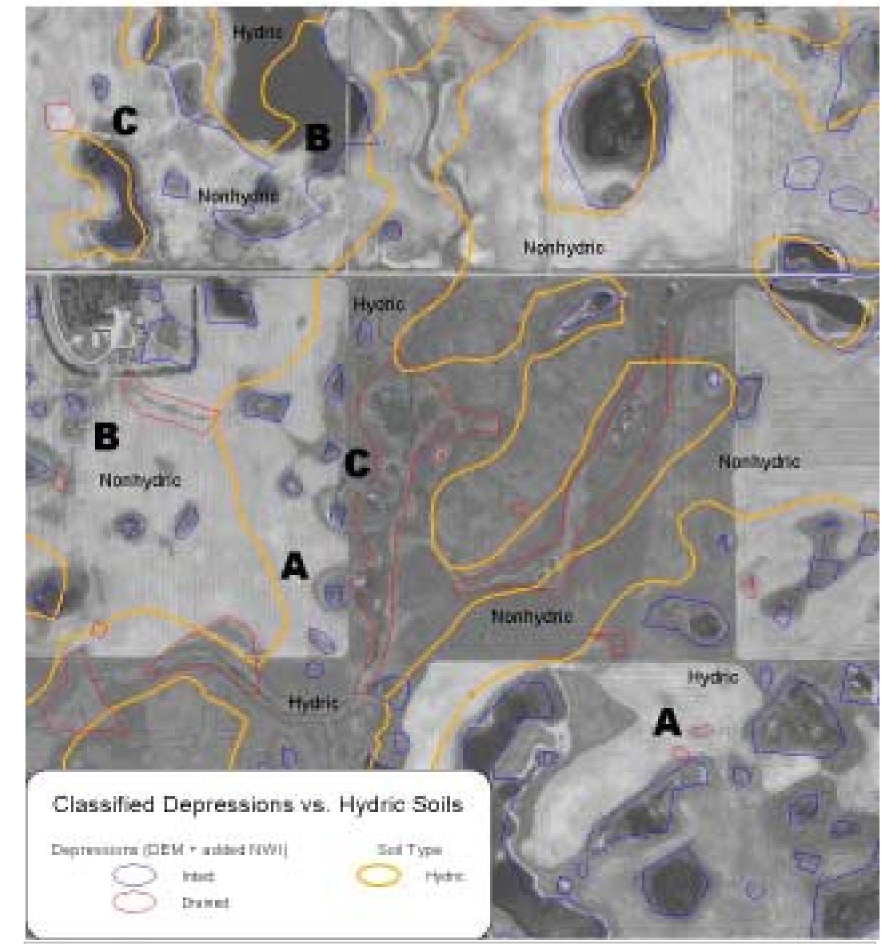



**(b) NWI polygons versus soil type (hydric/non-hydric)**




Note: Figure 3-3 (b) depicts the original NWI coverage for this area. It is not limited to the NWI polygons added to the classified depression coverage.

**(c) Close-up: Classified depression polygons versus soil type (hydric/non-hydric) over aerial photo**




Areas to note:
A - Hydric soil polygons often encompass a large area around multiple depressions.
B - Depressions may be found in nonhydric soil areas.
C - Hydric soil polygons may pick up some depression area missed by the DEM or NWI. However, it is difficult to distinguish these areas because of the issue described in note A.

Figure 3-2. Comparison of depressions and soil type.

### 3.3.4. Categorizing Farmed Depressions

In general, farmed over depressions with visible furrows but no clearly visible drainage were considered non-functional and classified as "possibly drained". Some of these depressions could dry early in the year, allowing farming during the growing season while still functioning as intact wetlands. However, over the course of many years, some of the smaller farmed depressions may have been worked over (i.e., plowed, leveled) to an extent that their storage volume has been greatly reduced or even eliminated. In any case, the vast majority of farmed over depressions were small (less than 0.25 acre) and shallow (less than 0.5 foot average depth). Because these depressions represent a small percentage of the total possibly drained depression area and even less of the total volume, a different classification for these depressions would have had little effect on the volumetric possibly intact and possibly drained totals. Moreover, depressions with less than 0.5-foot average depth – which includes most of these depressions – were *not* considered for restoration in this study (see Section 6). Field verification would be required to definitively assess the functionality of the farmed depressions.

### 3.3.5. Splitting Depressions

In a few cases, a large DEM-generated depression polygon encompassed both possibly drained and possibly intact depression areas, making it more difficult to classify. In order to improve the accuracy of the classification in these cases, the large polygon was split – multiple times, if necessary – and the resulting depressions were classified, as appropriate. Area, volume, and average depth were recalculated for each of these depressions.

### 3.3.6. Quality Assurance/Quality Control

Quality assurance/quality control (QA/QC) procedures were implemented throughout the classification process. Training of all personnel was conducted prior to classification, difficult-to-classify depressions were reviewed, and a comprehensive QA review was conducted following classification of all DEM-derived depressions. In addition, a final quality assurance check was conducted after the non-DEM polygons had been added and classified, in order to confirm the following:

- No depressions were left unclassified.
- Each depression was categorized consistent with the classification procedure (i.e., flow chart).
- Depressions representing drainage ways and streams/rivers were classified as "other".
- No polygons were overlapping, between the DEM and non-DEM polygons, within the DEM polygons, and within the non-DEM polygons.
- Depression surface area, volume, and average depth were calculated correctly.
- Each depression was assigned a unique polygon ID.

During the course of the final QA review, a large number of non-DEM polygons were found to be inconsistent with the flow chart classification procedure. Most of these occurred in the Hurricane Lake and Mauvais Coulee subwatersheds where the DEM was based on 10-foot contour interval. The main reason for this difference was that the original classification had not been performed at a sufficient scale (i.e., the classifier did not zoom in far enough on the aerial photo). At what appeared to be a reasonable scale, many small polygons appeared to be drained; however, upon closer inspection, they fit the criteria for possibly intact depressions. During the final QA review, a very detailed and comprehensive inspection of polygons in the entire upper basin watershed resulted in approximately 10 percent less possibly drained depression area than was originally classified. This accounts for the difference between the final results, presented in the next section, and the preliminary results presented at the Second Review Meeting on February 21, 2001.

## 3.4. <u>SUMMARY OF RESULTS</u>

The depression delineation and classification process for the entire 2,616-$mi^2$ upper basin watershed (exclusive of Stump Lake and Devils Lake local drainage area) yielded the results shown in Table 3-3 below, and illustrated in Figure 3-3. The total number of depressions is believed to be conservative (i.e., underestimated) to some degree, for the reasons described in Section 3.6.3. These results are limited by the quality of the available data and the lack of field verification. These limitations are further discussed in Section 3.6.1 and recommendations for future studies are included in Section 3.7.

Table 3-3. Estimates of possibly intact and possibly drained depressions in the upper basin.

| **Depression Type** | **Count** | **Area** (acres) | **Volume** (acre-ft) |
|---|---|---|---|
| Possibly <u>Intact</u> [1, 2] | 63,458 | 201,990 | 481,604 |
| Possibly <u>Drained</u> [1, 3] | 52,210 | 92,429 | 132,729 |
| *Total* | *115,668* | *294,419* | *614,333* |

<u>Notes</u>:

(1) Based upon the available data and classification procedure, these depressions were classified as either "intact" or "drained". However, because field verification was not performed, the modifier "possibly" was adopted.

(2) "Possibly intact" depressions may be fully intact, mostly intact, or likely intact (i.e., appears intact, but not definitively so). The presence of standing water was not a prerequisite for classifying a depression as "possibly intact" because water in a shallow depression could be fully lost to evaporation.

(3) "Possibly drained" depressions may be fully drained, mostly drained, partially drained, likely drained (i.e., appears drained, but not definitively so), filled-in, or otherwise non-intact or non-functional. The clear presence of a man-made drain was not a prerequisite for classifying a depression as "possibly drained".

The possibly intact and possibly drained depression totals (count, area, and volume), broken down by subwatershed, are provided in Table 3-4. Depression area as a percentage of subwatershed area is shown in Table 3-5.

Appendix C includes the depression totals versus average depth for the entire upper basin watershed, as well as by the individual subwatersheds.

Table 3-4. Estimates of possibly intact and possibly drained depressions by subwatershed.

| **Subwatershed** | **Depression Type** | **Count** | **Area** (acres) | **Volume** (acre-ft) |
|---|---|---|---|---|
| Calio Coulee | Possibly Intact [1, 2] | 1,842 | 7,820 | 15,494 |
| | Possibly Drained [1, 3] | 2,103 | 7,838 | 12,598 |
| | *Total* | *3,945* | *15,658* | *28,092* |
| Comstock | Possibly Intact | 2,465 | 4,726 | 11,110 |
| | Possibly Drained | 790 | 832 | 1,650 |
| | *Total* | *3,255* | *5,558* | *12,760* |
| Edmore Coulee | Possibly Intact | 8,550 | 53,702 | 130,432 |
| | Possibly Drained | 7,919 | 26,925 | 41,138 |
| | *Total* | *16,469* | *80,627* | *171,570* |
| Hurricane Lake | Possibly Intact | 12,571 | 24,750 | 70,722 |
| | Possibly Drained | 8,736 | 4,831 | 7,793 |
| | *Total* | *21,307* | *29,581* | *78,515* |
| Mauvais Coulee | Possibly Intact | 31,891 | 81,390 | 182,192 |
| | Possibly Drained | 27,172 | 26,465 | 30,328 |
| | *Total* | *59,063* | *107,855* | *212,520* |
| St. Joe Coulee | Possibly Intact | 2,171 | 8,250 | 15,001 |
| | Possibly Drained | 1,506 | 6,206 | 8,859 |
| | *Total* | *3,677* | *14,456* | *23,860* |
| Starkweather Coulee | Possibly Intact | 3,968 | 21,353 | 56,653 |
| | Possibly Drained | 3,984 | 19,332 | 30,363 |
| | *Total* | *7,952* | *40,685* | *87,016* |

Notes:

(1) Based upon the available data and classification procedure, these depressions were classified as either "intact" or "drained". However, because field verification was not performed, the modifier "possibly" was adopted.

(2) "Possibly intact" depressions may be fully intact, mostly intact, or likely intact (i.e., appears intact, but not definitively so). The presence of standing water was not a prerequisite for classifying a depression as "possibly intact" because water in a shallow depression could be fully lost to evaporation.

(3) "Possibly drained" depressions may be fully drained, mostly drained, partially drained, likely drained (i.e., appears drained, but not definitively so), filled-in, or otherwise non-intact or non-functional. The clear presence of a man-made drain was not a prerequisite for classifying a depression as "possibly drained".

Table 3-5. Depression area, as percent of total subwatershed area.

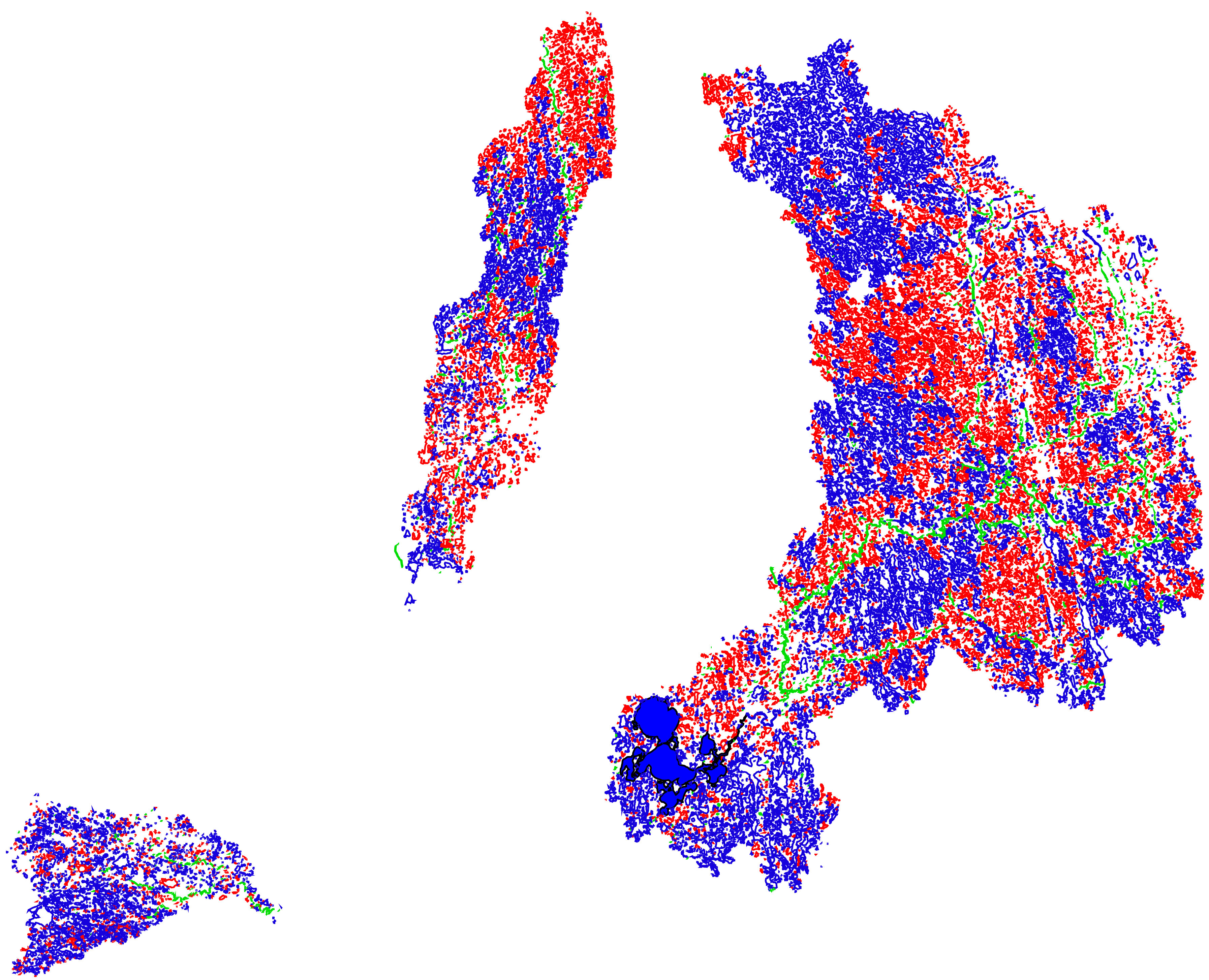
| **SUBWATERSHED** | **DEPRESSION AREA PERCENTAGE** (depression area/subwatershed area) | | |
|---|---|---|---|
| | **Possibly Intact** [1, 2] | **Possibly Drained** [1, 3] | **Total** |
| Calio Coulee | 9.4% | 9.5% | 18.9% |
| Comstock | 11.3% | 2.0% | 13.3% |
| Edmore Coulee | 14.1% | 7.1% | 21.2% |
| Hurricane Lake | 10.4% | 2.0% | 12.4% |
| Mauvais Coulee | 12.6% | 4.1% | 16.7% |
| St. Joe Coulee | 10.3% | 7.8% | 18.1% |
| Starkweather Coulee | 10.4% | 9.4% | 19.9% |

Notes:

(1) Based upon the available data and classification procedure, these depressions were classified as either "intact" or "drained". However, because field verification was not performed, the modifier "possibly" was adopted.

(2) "Possibly intact" depressions may be fully intact, mostly intact, or likely intact (i.e., appears intact, but not definitively so). The presence of standing water was not a prerequisite for classifying a depression as "possibly intact" because water in a shallow depression could be fully lost to evaporation.

(3) "Possibly drained" depressions may be fully drained, mostly drained, partially drained, likely drained (i.e., appears drained, but not definitively so), filled-in, or otherwise non-intact or non-functional. The clear presence of a man-made drain was not a prerequisite for classifying a depression as "possibly drained".



# Figure 3-3

Devils Lake
Upper Basin

Classified
Depressions

WEST
CONSULTANTS, INC.

## 3.5. COMPARISON TO PREVIOUS STUDIES

### 3.5.1. Estimates of Upper Basin Wetland/Depression Area

Upper basin storage has been addressed in a number of previous studies, which were reviewed in the first phase of this study (see WEST Consultants, 2000). The most recent and/or frequently referenced estimates of wetland/depression surface area are provided in Table 3-6.

Estimates of possibly intact (or "existing") depression area are very similar between this study and the NDSWC and USFWS estimates. In contrast, estimates of drained surface area range from a low of 37,000 acres (NDSWC) to a high of 189,000 acres (USFWS). The current study's possibly drained depression area estimate of 92,429 acres is somewhat lower than the mean of these two values. The NDSWC estimate of drained wetland area is based on the NRCS wetland maps and the NDSWC's permitted drain database. Only depressions with distinct drains were considered, and only the area that appeared to be part of a wetland in the past was included (i.e., the full depression area was not used). In contrast, the USFWS estimate is based on the maximum depression area of the wetlands.

Table 3-6. Summary of depression area estimates from different studies.

| SOURCE OF ESTIMATE | | SURFACE AREA (ACRES) | | |
|---|---|---|---|---|
| **Agency/Authors** | **Date** | **Possibly Intact** [1] | **Possibly Drained** | **Total** |
| N.D. State Water Commission | May 1999/ July 1998 | 181,000 | 37,000 [2] | 218,000 |
| U.S. Bureau of Reclamation | Feb. 1999 | -- | 65,250 [3] | -- |
| WEST Consultants, Inc. | Apr. 2001 | 201,990 | 92,429 | 294,419 |
| U.S. Fish and Wildlife Service | Jan. 1997 | 181,000 | 189,000 [4] | 370,000 |
| Ludden, Frink, and Johnson | Jan. 1983 | -- | -- | 412,000 [5] |

Notes:

(1) The intact depression surface area estimates do not include lakes in the upper basin, which comprise an additional 30,000 to 40,000 acres, depending on the study.

(2) Includes areas not in the upper basin that contributes to Devils Lake, but not to Stump Lake.

(3) Includes areas not in the upper basin that contribute to Devils Lake, but not to Stump Lake. Drained surface area is extrapolated from a Bureau of Reclamation study of the St. Joe/Calio Coulee subwatersheds. Stated drained area is 75,000 acres, less 13 percent which contributes to Stump Lake = 65,250 acre-feet.

(4) Includes areas not in the upper basin that contribute to Devils Lake. Drained surface area is extrapolated from a U.S. Fish and Wildlife study of 60,000 acres in the upper basin.

(5) Includes areas not in the upper basin that contribute to Devils Lake.

The WEST estimate is primarily based on the maximum depression area for the DEM-derived depressions. The NWI polygons, which did not necessarily represent the maximum depression area, compose only 11 percent of the total possibly drained surface area. Previous objections have been made to using maximum depression storage in considering the effect of upper basin storage on Devils Lake levels because the depressions would not necessarily fill up, depending on their contributing areas. The hydrologic model used by WEST addresses this valid concern by utilizing the contributing areas to the depressions in the modeling approach. Depressions in the model with insufficient drainage area will not fill up during a rainfall-runoff event. A more detailed discussion is included in Section 4 and Appendix A.

### 3.5.2. Comparison with USGS Study of Starkweather Coulee

The USGS conducted a study of runoff and storage in a portion of the Starkweather Coulee subwatershed (Vining, report to be released). The USGS study area was located upstream of a gaging station (Gage 05056239) on Starkweather Coulee. The total depression area estimates from this study and the USGS study are similar, with the WEST estimate about 8 percent higher. For total depression volume, the WEST value is about 13 percent lower than the USGS estimate. A comparison of depression information from the USGS study and the current WEST study is provided in Table 3-7 below.

Table 3-7. Depression area and volume estimates from USGS and WEST studies.

| Study | Drainage Area ($mi^2$) | Depression Area (acres) | Depression Volume (acre-ft) |
|---|---|---|---|
| U.S. Geological Survey | 262 | 30,890 | 68,270 |
| WEST Consultants | 252 | 33,323 | 59,645 |

### 3.5.3. Comparison with USBR Study of St. Joe/Calio Coulee

The U.S. Bureau of Reclamation (USBR) conducted a pilot study of the St. Joe/Calio Coulee (SJCC) subwatersheds (Bell et al., 1999). A comparison of results from the pilot study and the current WEST study is provided in Table 3-8 below.

Table 3-8. Possibly intact and possibly drained depression totals for USBR and WEST studies.

| STUDY | POSSIBLY INTACT | | POSSIBLY DRAINED | |
|---|---|---|---|---|
| | Count | Area (acres) | Count | Area (acres) |
| Bureau of Reclamation | 4,309 | 21,505 | 1,898 | 4,749 |
| WEST Consultants | 4,013 | 16,070 | 3,609 | 14,044 |

Some of the variation between the depression totals may be explained by the following differences between the two studies:

- USBR limited their identification to possibly drained "wetlands." That is, moist or wet depressions with visible drains were not classified as a drained "wetland" if they did not have residual wetland vegetation associated with them. WEST classified possibly drained depressions only, and did not distinguish whether they could be classified as wetlands or not.

- USBR used stereoscopes to interpret June/August 1997 color infrared, 1:12,000 (1 inch equals 1,000 feet) photographs for drained wetland perimeters. The surface area was based on a "stain" line, representing the area that had been a wetland in the past. WEST is reporting the full depression area at the pour point for each depression from the DEM data and supplemented by adding depressions that did not show up in the DEM data but are shown in the 1979 NWI database.

- Total estimate of possibly drained and intact depressions by WEST is 4,013 plus 3,609 or 7,622. This is 96 percent of the total count of drained and intact wetlands in the National Wetlands Inventory data from 1979 (6,410 plus 1,571 or 7,981). Total intact and drained wetlands by USBR is 4,309 plus 1,898 or 6,207. Therefore, the USBR study had only 77 percent of the total count from the National Wetlands Inventory.

- The USBR study area for SJCC was reported as 233 square miles. The SJCC study area total for WEST is 254 square miles (9 percent larger).

- The minimum mapping unit used by the USBR is 0.1 acre. WEST delineated depressions having surface areas less than 0.1 acre.

## 3.6. DISCUSSION OF DELINEATION AND CLASSIFICATION PROCESS

There are both limitations and advantages to the depression classification process used in the current study.

### 3.6.1. Limitations

The limitations, with varying degrees of importance, include the following:

- No field verification was conducted due to time constraints and snow cover during the study period.

- Partial drainage was not accounted for (i.e., depressions were categorized as "possibly intact" or "possibly drained", but not "partially drained").

- Some individual depression classifications are subject to interpretation.

- Classification was based upon aerial photos representing one point in time.

- A small number of the aerial photos were darker than normal, making the depressions more difficult to categorize.

- The resolution of the aerial photos was not fine enough to identify: (1) the location of fully drained depressions not captured by the DEM nor the NWI data; and (2) the location of some of the drainage ditches.

### 3.6.2. Advantages

While there are a number of limitations to the classification process, there are also a number of important advantages of this classification process, including:

- Depressions were individually delineated and classified over the entire upper basin watershed.

- Physically-based delineation was achieved using the DEM, thus minimizing the need for extrapolation.

- Depressions were visually verified using aerial photos.

- Supplementary data were used (NWI, quad maps, flow direction).

- Quality assurance/quality control measures were utilized:

    - Training and supervision on classification process (e.g., classification flow chart).

    - Preliminary and final, comprehensive quality assurance checks of entire watershed.

### 3.6.3. Possible Underestimation of Depression Area and Storage

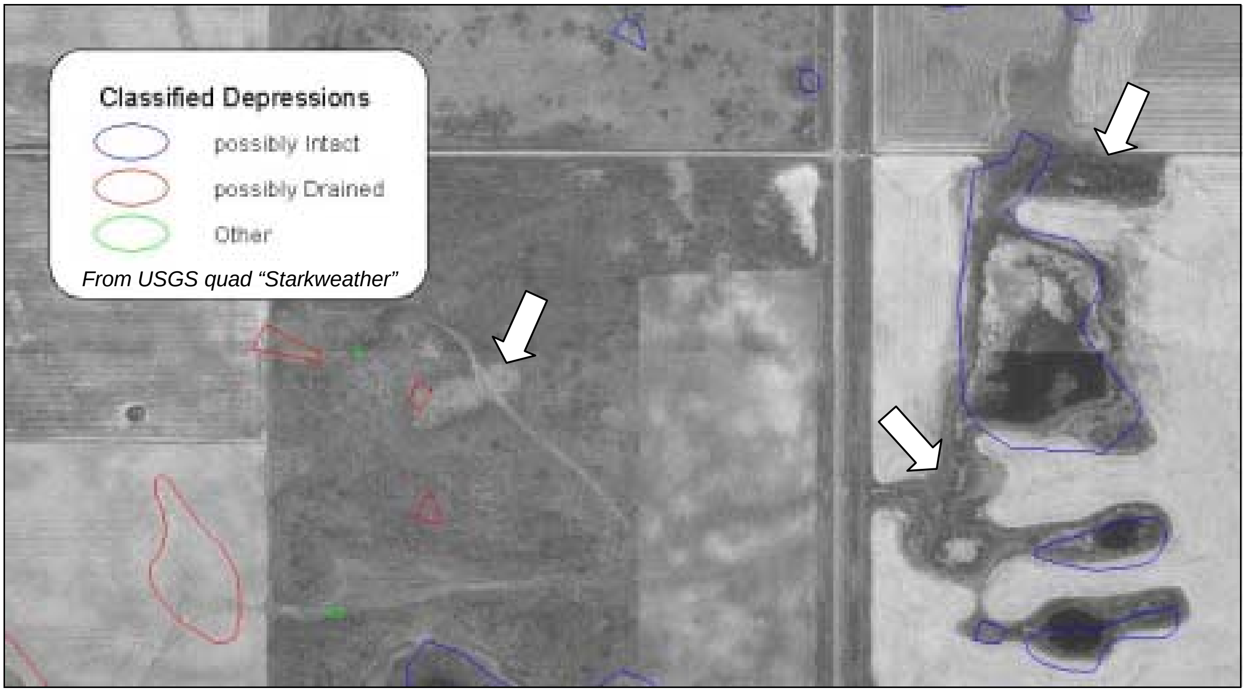
Due to the comprehensive nature of the depression delineation and classification process, the results given in Section 3.4 represent very reasonable estimates of upper basin depression area and volume. Overall, however, the estimates of possibly intact and drained depression area and volume totals are believed to be conservative (i.e., underestimated) to some degree for the following reasons:

- The depression area and available storage were underestimated to some degree because the added NWI polygons do not represent the maximum depression area.

- A number of DEM depression polygons appeared to be smaller in area than the corresponding depressions on the aerial photos. The underestimated area and volume was only partly offset by the presence of larger-than-appropriate DEM depression polygons.

- There were areas, especially within the 10-foot contour interval region, where depressions were missed by both the DEM grid and the NWI data set (see Figure 3-4).

For the reasons stated above, it is likely that a more intensive analysis would result in a greater number of depressions.




Note: *The arrows point to some of the apparent depression areas that were missed by the DEM grid and NWI data.*

Figure 3-4. Example of missed depression area.

### 3.7. RECOMMENDATIONS FOR FUTURE STUDIES

The goal of this study was to evaluate the impacts of upper basin storage on the volume of runoff entering Devils Lake. This evaluation required that the volume of intact and drained upper basin storage elements (i.e., depressions) be estimated to conduct the hydrologic modeling. The depression delineation and classification process was extensive, physically-based, reproducible, and conducted based upon the study objective. The results presented in this study are reasonable estimates of depression area and volume. However, the accuracy of the delineation and classification of some of the individual depressions was limited by the available data and project constraints. For future studies, it is recommended that this work be refined as follows:

- Obtain historical aerial photos, preferably from the 1950's when drainage activity was minimal, to assist in identifying depressions in those areas missed both by the DEM grid and NWI data. These historical photos could also be compared to current photos to verify the depression classification.

- Perform extensive field verification to locate drainage ditches, determine the functionality of the farmed depressions, and verify the depression classification.

- Utilize the 1997 color infrared photography, which is higher resolution than the DOQ's used in this study, to refine the depression delineation and classification.

- Obtain more refined soil data to develop relationships between depression area and hydric soils.

- Include more classifications such as "partly drained". Separate depressions that have drainage ditches from those that have been disturbed by other activities such as farming.

- Obtain higher resolution digital terrain data, especially in those areas currently modeled from the 10-foot contour interval data.

# 4. HYDROLOGIC MODELING APPROACH

## 4.1. HEC-HMS MODELING EFFORTS AND DEFICIENCIES

Originally, the hydrologic model of the Devils Lake basin was going to be developed using the HEC Hydrologic Modeling System (HEC-HMS), Version 2.1.1 (Hydrologic Engineering Center, 2001). However, it was determined that the modeling approach was not sufficient for the following reasons:

- The Soil Moisture Accounting (SMA) algorithm did not adequately simulate depression storage. The depression storage component of SMA was spread over an entire subbasin, which is analogous to having a shallow pond covering the entire subbasin. Consequently, depression storage had to be depleted before evapotranspiration from the soil occurred. When simulating the depression storage in the Devils Lake basin, the full depression storage volume was available every year, which is not consistent with field observations. The method over-predicted the hydrologic impact of depression storage and, therefore, could not be used to analyze upper basin storage in the Devils Lake basin.

- Reservoir elements could be used to model the depression storage. However, HEC-HMS does not apply precipitation or evaporation to the reservoir elements. Therefore, additional subbasin elements would need to be added to account for the precipitation. A trial case of this was constructed for one subwatershed. An average daily evaporation could be estimated by converting the evaporation volume to outflow from the reservoir, and diverting the evaporation outflow from the model. This method requires a minimum of four hydrologic modeling elements for each subbasin. This combination of elements could not be constructed by HEC-GeoHMS. Therefore, the elements and associated inputs had to be input manually into HEC-HMS. The average subbasin size was one square mile, with a total of 2,618 subbasins in the trial subwatershed. Manual model construction was extremely time consuming for a hydrologic model of this magnitude and was not feasible under the project time constraints.

- HEC-HMS does not have a frozen ground algorithm. Since snowmelt is a major component of the annual runoff in the Devils Lake basin, a method had to be developed to simulate snowmelt runoff on frozen ground. Two HEC-HMS models had to be set up for each subwatershed to simulate frozen and unfrozen ground conditions. This resulted in having to start and stop runoff simulations twice each simulation year, renaming input files and relaunching the program. The evaporation and infiltration rates were different in the two models. Therefore, because of the manual entry of data into the models and the inefficiency of starting and stopping the simulations, the HEC-HMS modeling could not be completed within the project's time limit.

- It is difficult to extract data from HEC-HMS output. HEC-HMS writes all of its output to the HEC Data Storage System (DSS) format for each model element. The HEC-DSS fields contain daily data for at least 10,500 model elements. Since HEC-DSS is DOS-based, it is difficult to extract and summarize the model results such as total depression storage, changes in depression storage, annual evaporation, etc.

Therefore, because of these limitations and difficulties, HEC-HMS, in essence, had to be programmed from the outside, and tricked into modeling the processes in the Devils Lake basin. Therefore, a custom hydrologic model, which overcame many of the difficulties that HEC-HMS presented, was developed. The details of the custom model are presented in following section.

## 4.2. POTHOLE-RIVER NETWORKED WATERSHED MODEL

The Pothole-River Networked Watershed Model (PRINET) is a hydrologic model that utilizes topographic and climatic information to simulate a long-term process (generally from 20 to 50 years) of rainfall, evaporation, and water storage for a terrain with a substantial number of depressions (or potholes). The model was specifically developed to simulate soil storage, depression storage and runoff in the Devils Lake basin. PRINET could conceivably be applied to another watershed if the topographic and climatic data were available.

The PRINET application was written in Microsoft Visual Basic 6.0 (Visual Basic For Applications), inside a Microsoft Access database. Microsoft Access 2000 is required to run the application. Figure 4-1 presents a flow chart of calculations performed during the simulations.

Six subwatersheds, encompassing the upper basin of Devils Lake, were modeled by PRINET (see Figure 5-1 in Section 5). Each subwatershed was divided into numerous subbasins. There were 9,078 subbasins modeled in the upper basin, and the average subbasin area was 0.29 square miles. The smallest subwatershed modeled (Comstock) had 257 subbasins, and the largest (Mauvais) had 3,176. The subbasins in each subwatershed were networked; that is, the exact sequence of flow between subbasins was specified for each subwatershed.

A detailed technical description of the model is included in Appendix A. The computational sequence and the hydrologic processes modeled are summarized below. The model performs the following ten computations on a daily basis:

1. Determine precipitation and evaporation for each day.

2. Add precipitation to the soil moisture and to the depressions.

3. Determine infiltration of precipitation into the soil, and update the soil moisture level accordingly.

4. Any precipitation that does not infiltrate runs off into intact depression storage. A separate accounting is made of on-river depressions (those that intersect the river network) and off-river depressions (those that do not intersect the river network).

5. If upstream subwatersheds exist, they are modeled as sources of flow into the downstream subwatershed model at the appropriate location.

6. Evaporation is calculated for each subbasin's intact depressions, and the water storage volume is reduced accordingly.

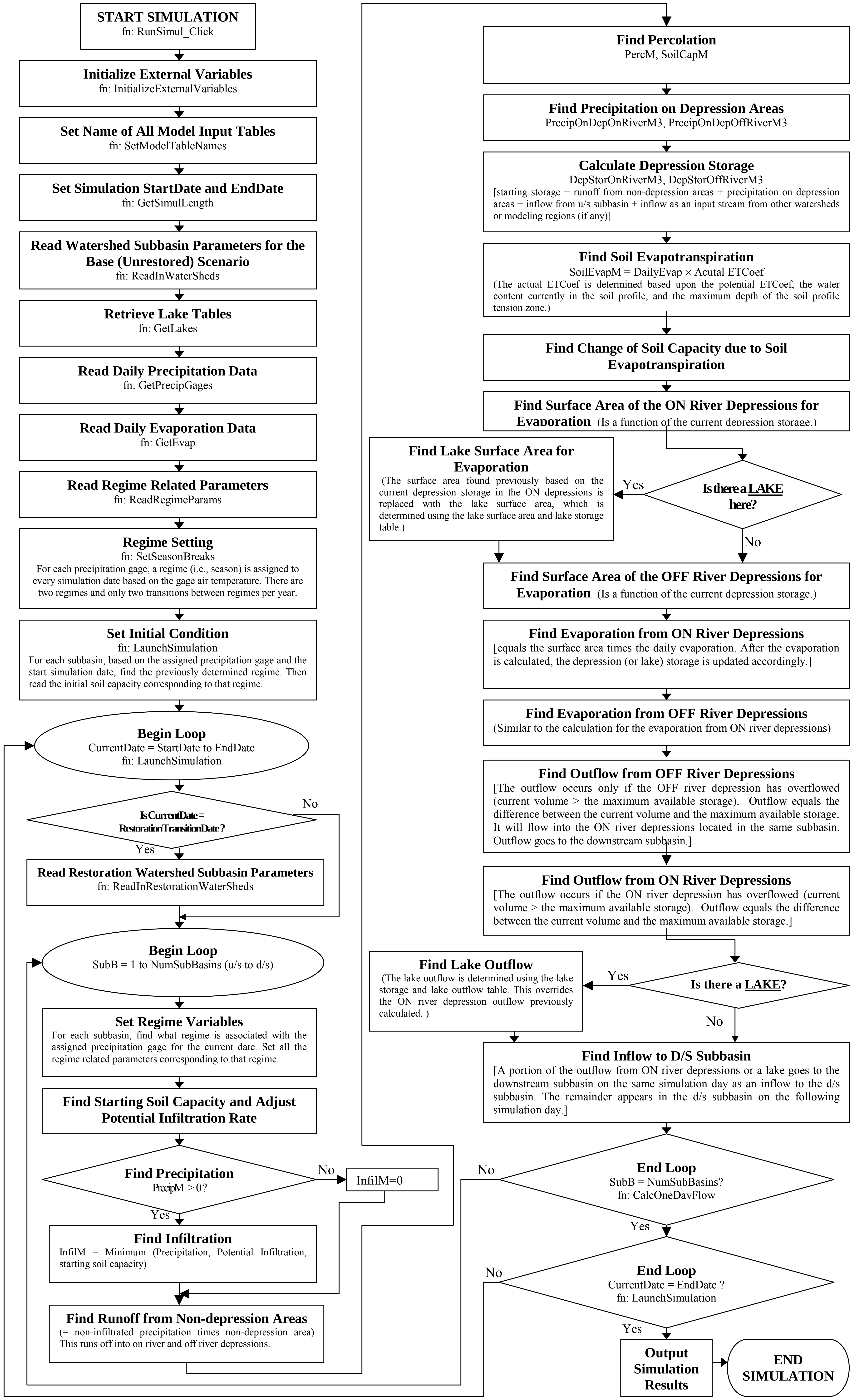



Figure 4-1. Pothole-River Networked Watershed Model (PRINET) Flow Chart.

7. Evapotranspiration is calculated for each subbasin's soil, and the moisture level is reduced accordingly.

8. Percolation is determined for subbasins where the soil is sufficiently saturated to permit percolation.

9. When the depression water volume of a subbasin's off-river depression storage exceeds the off-river depression storage capacity, the excess runs off into the on-river intact depression storage of the same subbasin.

10. When depression water volume of a subbasin's on-river depressions exceeds depression storage capacity, the water flows into the intact on-river depression storage of the next downstream subbasin, or to the outlet of the subwatershed if there are no downstream subbasins.

The outputs of PRINET include daily runoff volumes at the outlet of each subwatershed, as well as runoff at any subbasin in the subwatershed (if requested in the model before simulation runtime). Furthermore, information regarding aggregate depression storage and soil moisture is recorded on a daily basis for each simulation. Daily precipitation, infiltration, and percolation volumes for the subwatershed are also recorded for each simulation day.

### 4.2.1. Seasonal Variables

Two seasons are required to simulate different climatic and soil conditions that occur during winter and non-winter conditions. An explicit frozen ground algorithm is not included in the model. Therefore, different infiltration and percolation rates associated with frozen and unfrozen ground conditions are required to adequately model snowmelt runoff. The parameters vary by season. The seasonal parameter variation is further discussed in Section 5.

There are two seasons established per year: the "High" season (which occurs in warm weather), and the "Low" season (which occurs in cold weather). For each subbasin, the transitions between seasons are determined using a 30-day moving average of the average daily temperature. When in the Low season, once the moving average temperature climbs above a certain "cutoff" temperature, the season changes to High. Similarly, when in the High season, once the moving average temperature drops below a certain cutoff temperature, the season changes to Low. The cutoff temperatures used to determine the season transitions were themselves calibration parameters, and were varied slightly between various subwatershed models. The algorithms used to assign seasons are explained in detail in Appendix A.

### 4.2.2. Precipitation

The average temperature and precipitation records were obtained from gage records (see Section 2). Each subbasin was assigned to a precipitation gage based primarily on its proximity to the gage.

Precipitation was divided into rainfall and snowfall, depending on the average daily temperature (the average of the recorded high and low temperatures). In the model, the average temperature dictates whether snow accumulates, snow melts, rain falls, or a combination occurs. The precipitation applied to each subbasin is the rainfall plus snowmelt combination.

The algorithm used to generate the snowmelt plus rain is identical to the degree-day method used in HEC-1, the U.S. Army Corps of Engineers Hydrograph Package (Hydrologic Engineering Center, 1990, p. 14 and p. A-43). The algorithm is summarized in the following paragraph.

First, rainfall is calculated as follows: If the average temperature is less than or equal to the freezing temperature plus 2 degrees Fahrenheit, all precipitation falls as snow and accumulates in the snow pack as a snow-water equivalent. If the average temperature is above the freezing temperature plus 2 degrees Fahrenheit, all precipitation falls as rain. Second, snowmelt is calculated. If the average temperature is above the freezing temperature, snowmelt (in inches) is calculated by multiplying the difference between the average daily temperature and the freezing temperature by a factor.

For all the gages in the Devils Lake basin, the freezing temperature was 34 degrees Fahrenheit and the factor was 0.07. This freezing temperature, as well as the factor of 0.07 (called "coefficient" in the HEC-1 documentation), is within the recommend ranges detailed in the HEC-1 documentation.

A more detailed explanation of this rain and snowmelt calculation is included in Appendix A.

### 4.2.3. Subbasin and River Network

Models were created by subwatershed (six subwatersheds were modeled.). HEC-GeoHMS was used to develop a "River" theme and a "Watershed" theme for each subwatershed.

In the "Watershed" theme, each subwatershed is divided into numerous subbasins. The subwatersheds were delineated to provide an average subbasin area of 0.29 square miles. Figure 4-2 shows the subbasin delineation for the Comstock subwatershed.

The other theme generated by HEC-GeoHMS, and used by PRINET, is a river theme. This is a network theme of river segments, as illustrated in Figure 4-3. Each river segment corresponds to exactly one subbasin. The "River" theme is used by PRINET to determine the sequence of flow between the subbasins in each subwatershed.

### 4.2.4. Depressions

Depressions were divided into two categories: those that intersected the river network (on-river depressions) and those that did not intersect the river network (off-river depressions). Figure 4-4 illustrates how each depression was assigned as on-river or off-river.

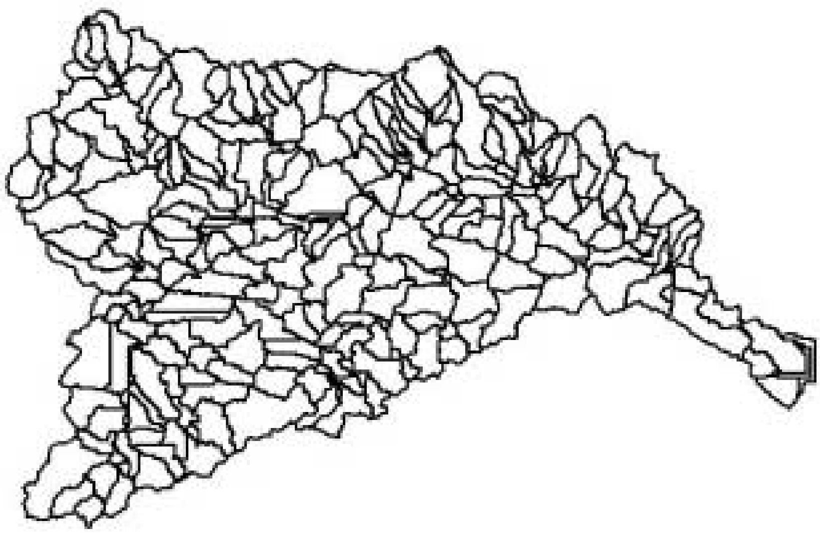


Figure 4-2.	Comstock subwatershed divided into individual subbasins by HEC-GeoHMS.

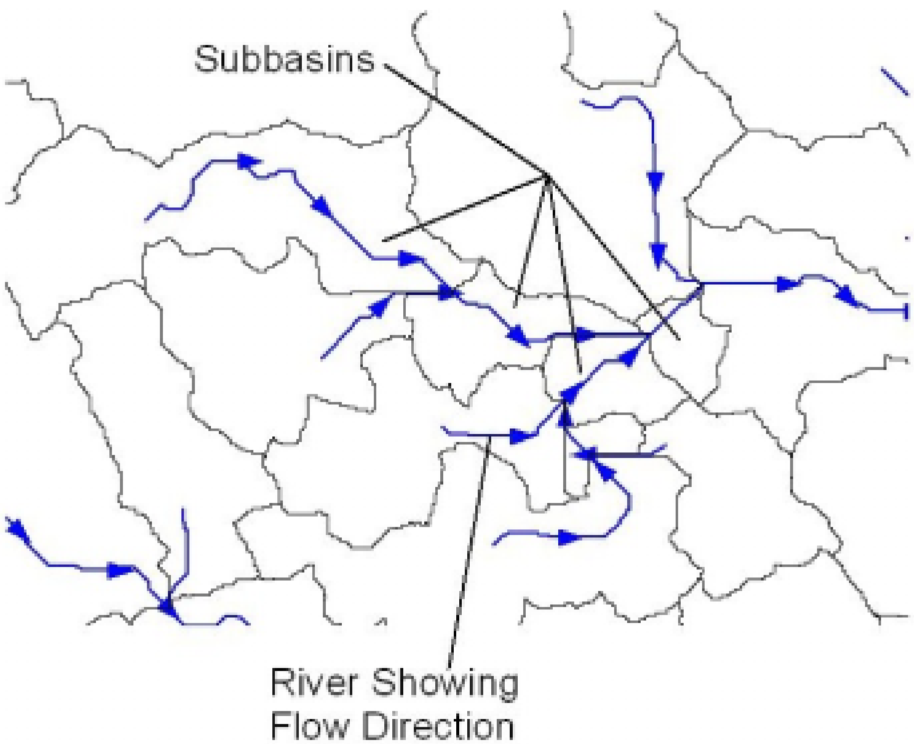



Figure 4-3. Networked river segments developed by HEC-GeoHMS delineation.

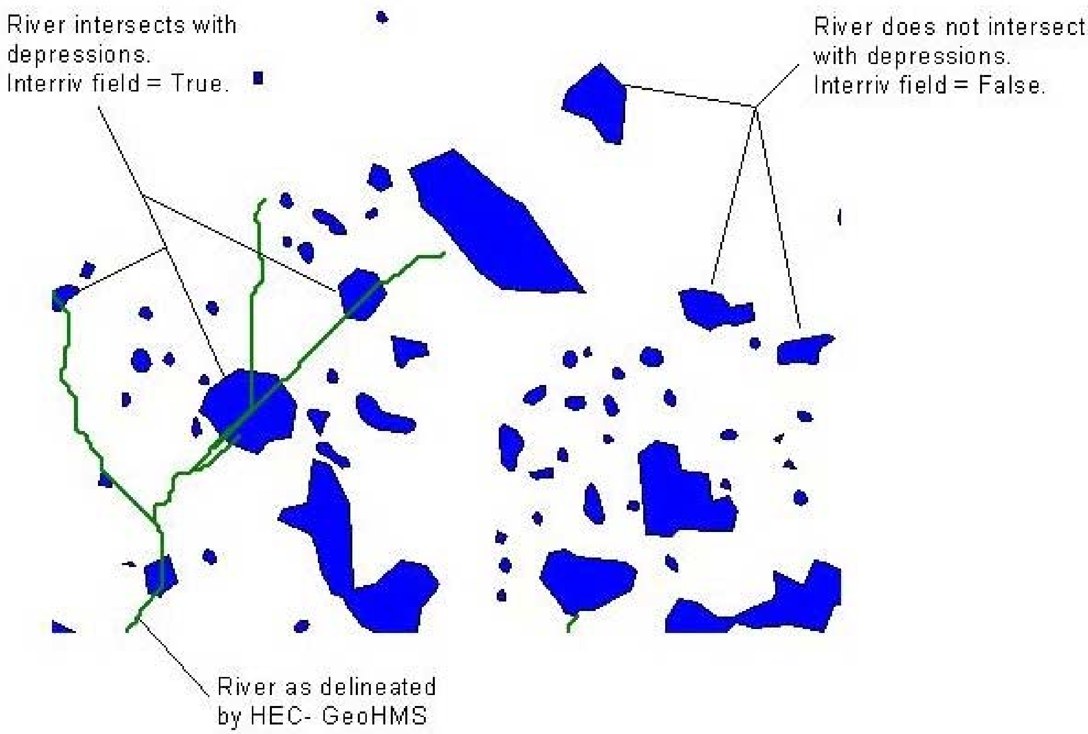



Figure 4-4. Representative area showing depressions and their intersection with the river theme delineated by HEC-GeoHMS.

Depression storage and surface area is accounted for by subbasin. The volumes and areas of all on-river depressions that appear in one subbasin are summed. The volumes and areas of off-river depressions are accounted for similarly. For example, in the Mauvais 6100 subwatershed model, there are 14,475 depressions (excluding those classified as *lake* or *other*), and 1,102 subbasins. Therefore, each subbasin has an average of 13 depressions assigned to it. Of these, only those depressions classified as possibly intact are used to calculate the depression volume and area. Flow from upstream subbasins cascades into the downstream on-river depressions. In contrast, only excess runoff from the immediate drainage area associated with the off-river depressions fills the off-river depressions. When the volume of the off-river depressions in a particular subbasin is exceeded, the excess flows into the on-river depressions.

Contributing drainage areas were calculated for every depression, both possibly intact and possibly drained, as illustrated in Figure 4-5. Since each depression is assigned to a subbasin, each subbasin's drainage area was defined as the sum of the contributing areas of the depressions in that subbasin. This replaces the subbasin area originally computed by HEC-GeoHMS.

These contributing drainage areas for each subbasin were further divided into two parts: (1) contributing area for on-river depressions, and (2) contributing area for off-river depressions. When surface runoff occurs in the model, the on-river depression volume receives runoff from the on-river contributing area, while the off-river depression volume receives runoff from the off-river contributing area.

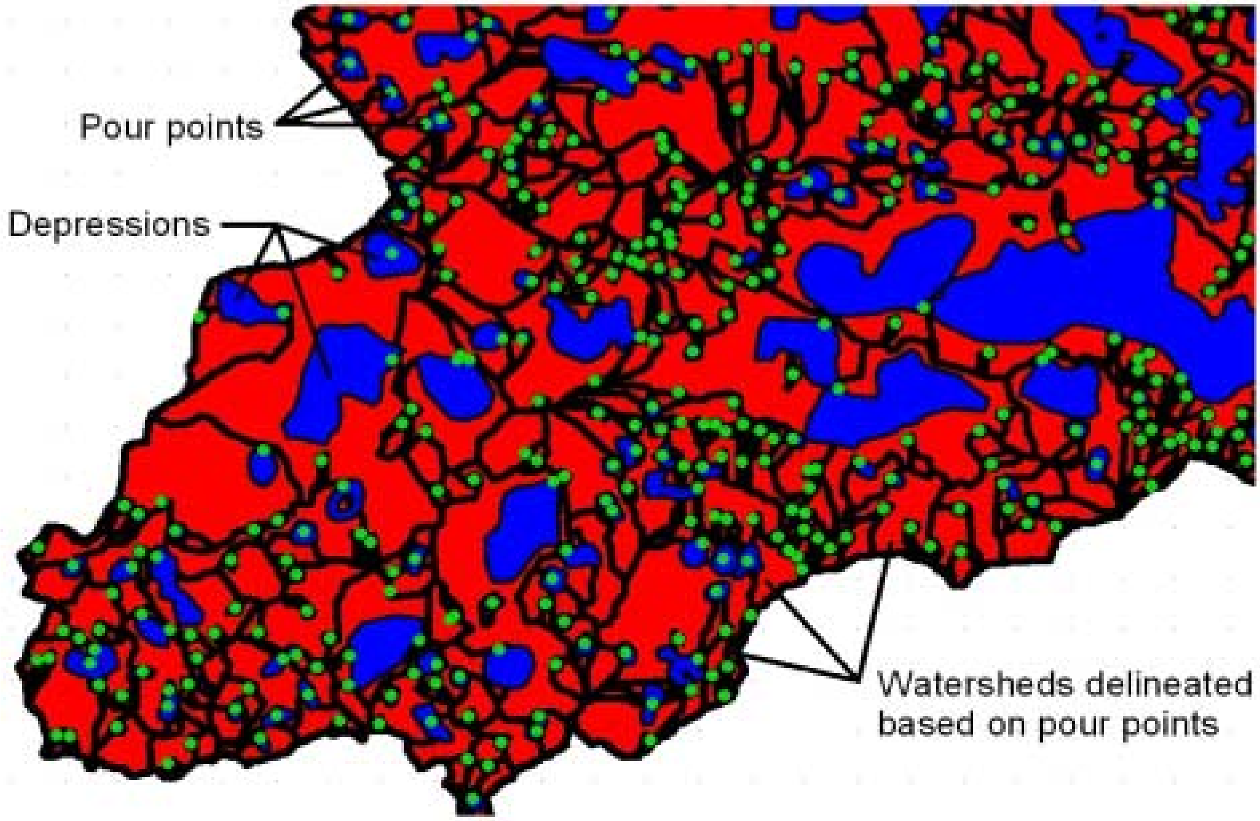



Figure 4-5. Contributing areas as delineated for each depression.

Precipitation on the intact depression surface area is added to the depression storage. Infiltration from the depressions is not modeled. Infiltration does occur on the non-depression land surface area.

#### 4.2.5. Soil Storage, Infiltration and Percolation

Illustrated in Figure 4-6 are some of the variables used in the soil moisture accounting routines in PRINET. All dimensions are depths of equivalent water; they do not correspond to physical depths nor do the dry or wet areas correspond to physical locations. PRINET tracks soil capacity (the dry portion of the soil storage) as a depth in meters for each subbasin on a daily basis. Soil capacity is decreased by infiltrated precipitation. Soil capacity is increased by evapotranspiration or percolation, the same as in HEC-HMS.

The soil is divided into two zones: the upper zone and the tension zone. The upper zone, which represents the water held in the pores of the soil, loses water to both evapotranspiration and percolation. The tension zone, which represents water attached to the soil particles, loses water only to evapotranspiration.

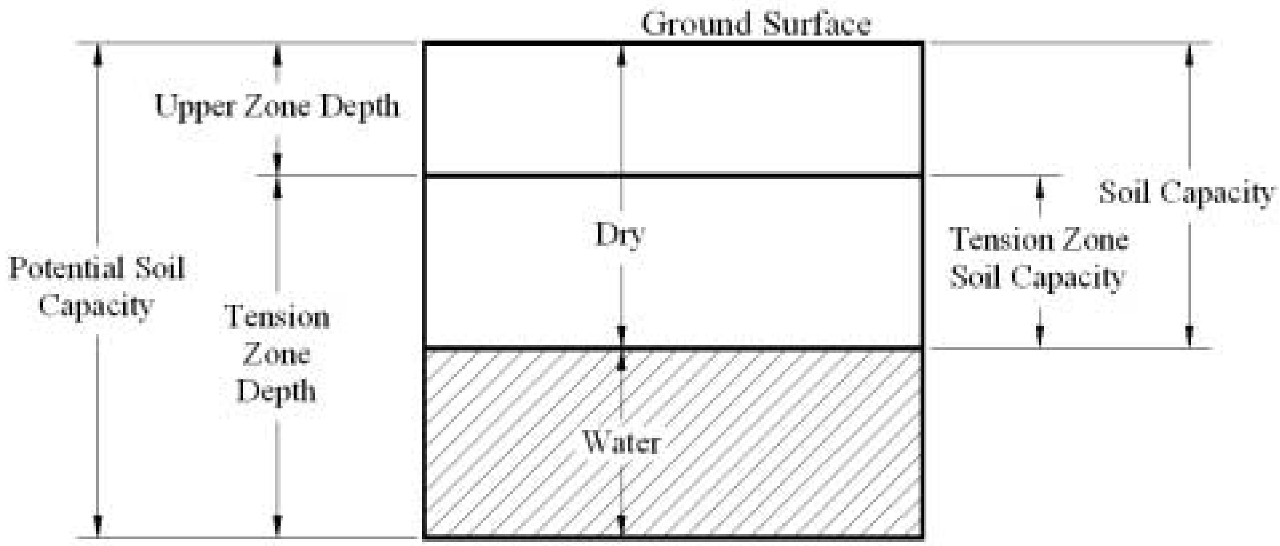



Figure 4-6. A schematic representation of soil profile, with variables labeled.

*4.2.5.1.* *Infiltration*

The actual infiltration rate (the amount of precipitation that can permeate into the soil on a given day) for a subbasin for a simulation day is based on the maximum potential infiltration rate, which is adjusted as a function of soil saturation. The actual potential infiltration for each time step is computed in the following equation, and illustrated in Figure 4-7.

*Actual potential infiltration = maximum potential infiltration * (soil capacity / potential soil capacity)*

Since soil capacity, which is re-computed daily, is a measure of dryness (see Figure 4-6), the maximum actual potential infiltration occurs when the soil is completely dry. As the soil capacity decreases (i.e., the soil becomes more saturated), the actual potential infiltration is reduced.

Percolation is the loss of infiltrated water to groundwater. Percolation, if it occurs, increases the soil capacity by the percolation amount. Percolation is only permitted by PRINET if the soil capacity on a given day is less than the upper zone depth (see Figure 4-6). Since the upper zone is generally very small, percolation only begins when the soil is close to saturation.

First, the actual potential infiltration rate for a subbasin is calculated. If the precipitation amount for the day exceeds that rate, all excess (the excess of precipitation minus infiltration) runs off into the depressions of the subbasin.

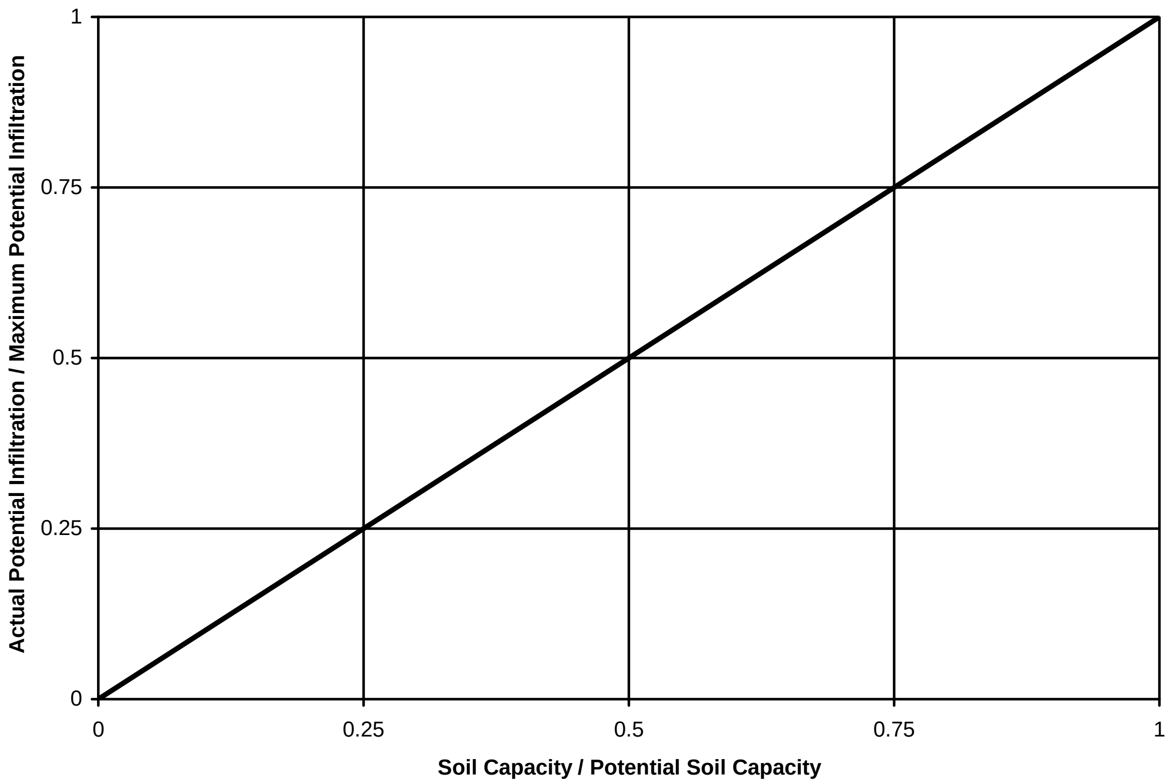



Figure 4-7. Relationship between soil capacity and actual potential infiltration.

### 4.2.6. <u>Soil Evapotranspiration</u>

The potential evapotranspiration for each simulation day is based on a Devils Lake evaporation value and an evapotranspiration coefficient. The daily Devils Lake evaporation values were computed by converting the monthly Devils Lake evaporation data provided by the USGS to daily values using the pattern observed at the Langdon pan evaporation gage (see Section 2.4 and Appendix A, Section A.2.4.3, for greater detail). This daily value, multiplied by the evapotranspiration coefficient, is the potential evapotranspiration (potential ET).

*Potential ET = Devils Lake Evaporation * ET Coefficient*

Actual soil evapotranspiration is calculated based on the relationship shown in Figure 4-8, which has been adapted from Bennett (1998). It is the method used by HEC-HMS to calculate evapotranspiration. As the soil moisture is depleted (i.e. the soil capacity increases), the evapotranspiration rate decreases. This represents the natural increasing resistance in removing water attached to soil particles.

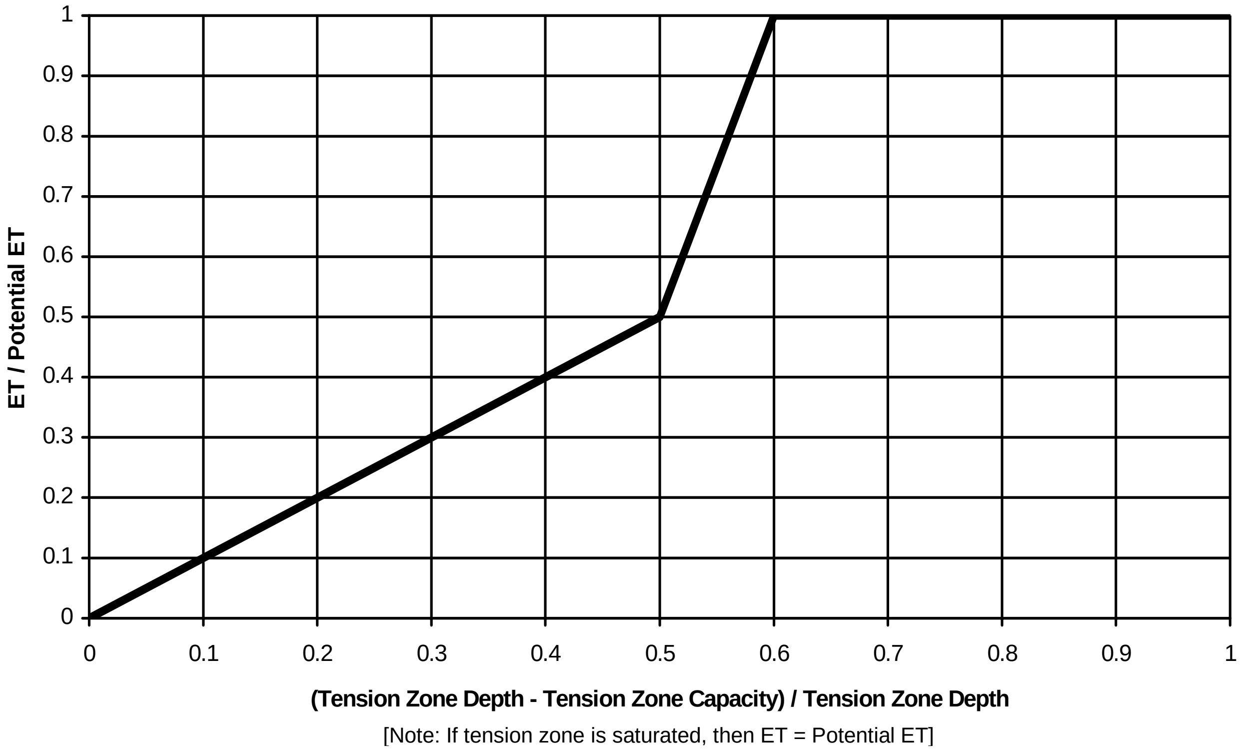



Figure 4-8. Relationship between actual ET and the tension zone capacity.

### 4.2.7. Depression Evaporation

The daily evaporation for the depression is computed using the methods described in Section 2.4 and in Appendix A (Section A.2.4.3). As the volume of water in depressions decreases, so does the surface area available for evaporation. The relationship used to compute the surface area available for evaporation is:

$$\textit{Surface Area For Evaporation} = \textit{Depression Surface Area When Full} * (\textit{Current Volume of Water} / \textit{Depression Volume})^{0.5}$$

For example, if the depression was 40 percent full, the surface area for evaporation would be $(0.40)^{0.5} = 0.632$ times the full depression surface area. The daily evaporation data is applied to this surface area to determine the volume of evaporation. Evaporation computations are performed by subbasin. Since each subbasin's depression volume is grouped by on-river and off-river depressions, the evaporation calculation is applied separately to each. The area-volume relationship in the equation above was compared to the actual area-volume relationships provided for the chain of lakes (see Appendix A-1). The assumed relationship was within the envelope spanned by the observed values.

Soil moisture was not modeled below intact depressions. Therefore, the soil evapotranspiration from the dry portions of the depressions was not computed.

# 5. HYDROLOGIC MODEL APPLICATION AND CALIBRATION

The PRINET model developed by WEST, and described in Section 4, was applied to the Devils Lake upper basin. This section describes the model calibration process, including the model regions and streamflow gages, precipitation gages, and the overall calibration approach. Also presented are the calibration of individual subwatersheds, a summary of calibration results, and a summary of calibrated parameters.

## 5.1. MODEL REGIONS AND STREAMFLOW GAGES

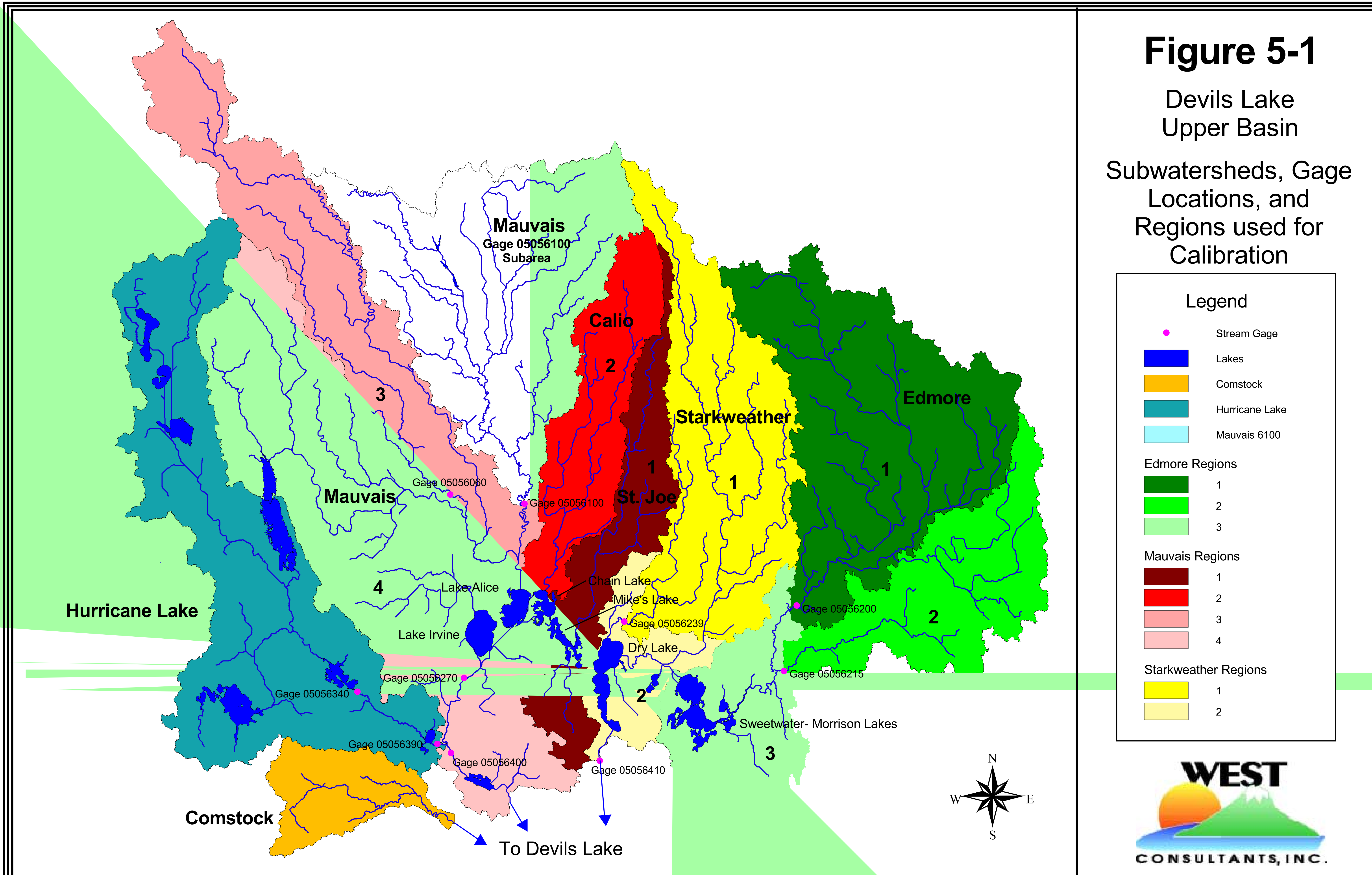
The Devils Lake upper basin was divided into 12 different regions for calibration, based on subwatershed boundaries and the location of streamflow gages. The total area, number of model subbasins, and calibration gages, if applicable, for each of the model regions are listed in Table 5-1. In addition, the locations of regions and calibration gages are shown in Figure 5-1. There are no streamflow gages within the Comstock, Calio Coulee, and St. Joe Coulee subwatersheds.

Table 5-1. Summary of subwatersheds, regions, and calibration gages.

| **Subwatershed** | **Region** | **Area** ($mi^2$) | **No. of Subbasins** | **Calibration Gage**(1) | **Description/Comments** |
|---|---|---|---|---|---|
| Comstock | | 65 | 257 | *none* | Parameters from Hurricane Lake subwatershed |
| Edmore Coulee | 1 | 322 | 1,199 | 6200 | Northern portion of Edmore subwatershed; drains to Gage 6200 on Edmore Coulee |
| | 2 | 168 | 622 | 6215 | Southeastern portion of Edmore subwatershed; drains to Gage 6215 on Edmore Coulee tributary |
| | 3 | 105 | 390 | *none* | Southwestern portion of Edmore subwatershed; located downstream of Gages 6200 and 6215 |
| Hurricane Lake | | 372 | 1,263 | 6390/6340 | Hurricane Lake subwatershed; drains to Gages 6390/6340 on Little Coulee |
| Mauvais, St. Joe, Calio Coulee | 1 | 125 | 388 | *none* | St. Joe Coulee subwatershed (2) |
| | 2 | 130 | 445 | *none* | Calio Coulee subwatershed (2) |
| | 3 | 252 | 840 | *none* | Northwest portion of Mauvais subwatershed; similar to Mauvais 6100 |
| | 4 | 430 | 1,503 | 6400/6270 | Rest of Mauvais subwatershed, excluding Gage 6100 area; primarily drains to Gages 6400/6270. Generally corresponds to 10-ft contour interval data. |
| Mauvais 6100 | | 328 | 1,102 | 6100 | Test calibration area in northeastern portion of Mauvais subwatershed |
| Starkweather Coulee | 1 | 252 | 853 | 6239 | Majority of Starkweather subwatershed; drains to Gage 6239 on Starkweather Coulee |
| | 2 | 67 | 216 | 6410 | Southwestern portion of Starkweather subwatershed; drains to Gage 6410 on Channel A |

(1) All USGS streamflow gages used for calibration begin with a "0505" designation. Therefore, the gages are referred to by their last four digits (e.g., "Gage 6200" instead of "Gage 05056200"). Only gages used for calibration are listed.

(2) The ungaged Calio Coulee and St. Joe Coulee subwatersheds were modeled as regions within the Mauvais Coulee model.




# Figure 5-1

Devils Lake Upper Basin

Subwatersheds, Gage Locations, and Regions used for Calibration

## 5.2. PRECIPITATION AND EVAPORATION DATA

One or more of six different precipitation gages (Belcourt, Cando, Church's Ferry, Edmore, Leeds, and Rolla) was used for each of the subwatersheds in the upper basin, as shown in Figure 5-2. The precipitation totals at each gage for water years 1979 through 2000 are provided in Section 2, Table 2-4. The 22-year totals for five of the six gages are within 5 percent of the average. The exception is the gage at Church's Ferry, which recorded approximately 13 percent less precipitation than the average. However, the annual variation between the gages is significant.

The model used monthly evaporation values for Devils Lake from 1980 through 1999 (see Table 2-6). The conversion of the monthly evaporation data to daily values is discussed in Section 2.4.

## 5.3. OVERALL CALIBRATION APPROACH

Since wetland drainage was allowed before the implementation of the wetland conservation provisions (i.e., "Swampbuster") in 1985, the amount of intact depression storage would be different before and after 1985. Therefore, the PRINET model calibration period was conducted for water years 1985 through 1999, a period with minimal changes to the depression topography and drainage network found in the upper basin. However, in order to provide a sufficient warm-up period, the model runs started on October 1, 1978 (start of water year 1979). The overall calibration approach included the following primary objectives:

- Matching the total computed and observed volumes to within approximately one percent for the entire calibration period (1985-99).

- Matching the pattern of dry, low runoff years in the late 1980s and the wet, high runoff years in the mid-to-late 1990s.

In addition, the calibration approach had the following secondary objectives:

- Matching the total computed and observed volumes for individual water years.

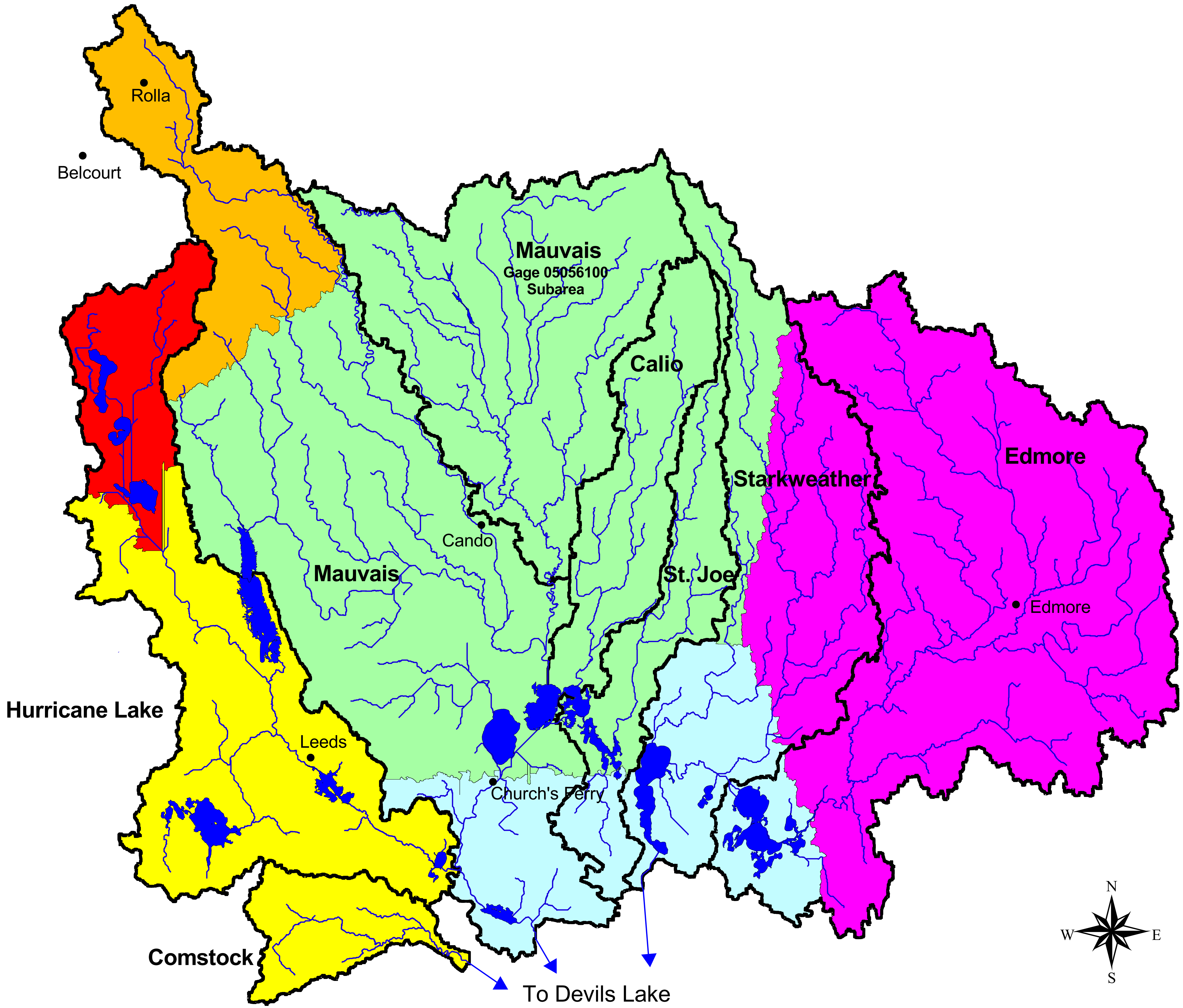
- Matching the peak flow and general hydrograph shape for individual water years.

Moreover, there were two important constraints put on the calibration process, which increased the validity of using the hydrologic model in a predictive mode. First, the same hydrologic parameters were used for the entire calibration period; no parameters were varied annually to account for year-to-year differences. Second, the number of parameters varied by calibration region was kept to a minimum. Infiltration rate and evapotranspiration coefficient were varied by model region (see Section 5.6). The temperature threshold for transitioning to the High regime was set within a small range of 45˚ to 46˚ F during model calibration. The temperature threshold for transitioning to the Low regime was a constant 35˚ F for all of the model regions.

# Figure 5-2

Devils Lake
Upper Basin

Precipitation Gage
Regions used for
Calibration




Legend

● Precipitation Gages

Precipitation Regions

Belcourt
Cando
Church's Ferry
Edmore
Leeds
Rolla

WEST CONSULTANTS, INC.

## 5.4. <u>INDIVIDUAL MODEL CALIBRATION</u>

Five individual models were calibrated (Mauvais 6100, Edmore Coulee, Starkweather Coulee, Hurricane Lake, and Mauvais Coulee). The sixth model, representing the ungaged Comstock subwatershed, used parameters from the Hurricane Lake model. As previously mentioned, the ungaged St. Joe and Calio Coulee subwatersheds are included in the Mauvais Coulee model. The results for all models and calibration gages are included in Appendix D.

### 5.4.1. <u>Mauvais Gage 6100 Subarea</u>

The Mauvais Gage 6100 subarea ("Mauvais 6100") served as the test calibration area for the upper basin hydrologic model. The test calibration yielded physically-based starting parameters that were consistent with the current body of knowledge concerning the Devils Lake upper basin. Most of the model parameters selected during test calibration were held constant for the other upper basin subwatersheds. The final calibrated parameters are presented in Section 5.6.

#### *5.4.1.1. <u>Calibration Results</u>*

At Gage 6100 on Mauvais Coulee, the computed results were low for water years 1987, 1994-95, and 1998-99. The computed results were high for water years 1985-86, 1989-90, 1993, and 1996 (see Appendix D). In discussing the calibration results at each gage, computed results are considered "low" for a particular water year if they are at least 5,000 acre-feet less than the observed volume. Likewise, computed results are "high" if they are at least 5,000 acre-feet higher than the observed volume.

Overall, the 1985 through 1999 computed flows at Gage 6100 were only 0.02 percent higher in total volume (423,946 acre-feet observed versus 424,013 acre-feet computed), with an annual correlation of 79 percent between the observed and computed volumes.

### 5.4.2. <u>Edmore Coulee Subwatershed</u>

The Edmore Coulee subwatershed has two streamflow gages, one on Edmore Coulee (Gage 6200), and another on an Edmore Coulee tributary (Gage 6215). The coulee and its tributary combine downstream of the gages, just upstream of the Sweetwater-Morrison Lakes. No streamflow gage is present at the subwatershed outlet, which is in close proximity to the outlet from Sweetwater-Morrison Lakes.

#### *5.4.2.1. <u>Revisions to HEC-GeoHMS Generated River Network</u>*

Initial calibration results showed that annual discharge volumes were consistently high when compared to observed values at Gage 6200, while annual volumes were consistently low at Gage 6215. These results seemed to indicate that the river network created by HEC-GeoHMS was connecting too much watershed area to Gage 6200, and too little area to Gage 6215. Upon closer inspection of the river network and aerial photos, one area was identified where the HEC-GeoHMS had incorrectly delineated the river network due to the flat terrain (see Figure A-7 in

Appendix A). The correct river network was noted and fixed within the hydrologic model by changing the downstream ("to") nodes for two river segments. This fix significantly improved the annual discharge volumes, as well as the computed versus observed correlation values, for both gages.

#### *5.4.2.2. <u>Calibration Results</u>*

For water year 1999, Gage 6200 did not begin recording until the beginning of May, instead of the usual March 1 start date. For this reason, the observed record missed the first large runoff event of the year, which was shown by other streamflow gages in the Edmore Coulee and Starkweather Coulee subwatersheds. For this reason, the total annual volume at Gage 6200 for water year 1999 was estimated based on the value at Gage 6215 given the high annual correlation between the two gages from 1986 through 1998.

At Gage 6200 on Edmore Coulee, the computed results were low for water years 1985-87, 1992, 1994-95, and 1998. The computed results were high for water years 1993, 1996-97, and 1999 (see Appendix D). Overall, the 1985 through 1999 computed flows at Gage 6200 were only 0.8 percent higher in total volume (342,785 acre-feet observed versus 345,612 acre-feet computed), with a very high annual correlation (88.3 percent) between the observed and computed volumes.

For Gage 6215 on the Edmore Coulee tributary, the computed results were low for water years 1986-87 and 1992-95. The computed results were high for water years 1996-99. Overall, the 1985 through 1999 computed flows at Gage 6215 were only 0.4 percent higher in total volume (311,011 acre-feet observed versus 312,244 acre-feet computed), with a very high annual correlation (90.3 percent) between the observed and computed volumes.

### **5.4.3. <u>Starkweather Coulee Subwatershed</u>**

Discharge from the Edmore Coulee subwatershed enters the Starkweather Coulee subwatershed via Webster Coulee, and flow from Webster Coulee enters Dry Lake. There was a streamflow gage (Gage 6225) on Webster Coulee at Webster; however, data is only available for a portion of one year (March 1 through September 30, 1994), so it was not used in the calibration. The majority of the Starkweather Coulee subwatershed drains to Gage 6239 located on Starkweather Coulee, which enters Dry Lake downstream of the gage. Discharge from Dry Lake enters Channel A and travels to the subwatershed outlet, which corresponds to Gage 6410 on Channel A. Discharge from Channel A represents one of the major inputs into Devils Lake.

#### *5.4.3.1. <u>Revisions to HEC-GeoHMS Generated River Network</u>*

Similar to the Edmore Coulee subwatershed, the HEC-GeoHMS generated river network for the Starkweather Coulee subwatershed needed to be changed at one location. The presence of a significant drainage connection on the Starkweather Coulee was visible on the aerial photo and digital quadrangle map, but was not picked up by the original river network. The corrected river network resulted in a much larger drainage area, and improved annual discharge volumes and correlation values at Gage 6239 on Starkweather Coulee.

#### 5.4.3.2. *Calibration Results*

At Gage 6239 on Starkweather Coulee, the computed results were low for water years 1985-87, 1992, and 1994-95. The computed results were high for water years 1993 and 1997-99 (see Appendix D). Overall, the 1985 through 1999 computed flows at Gage 6239 were only 0.2 percent higher in total volume (246,457 acre-feet observed versus 246,948 acre-feet computed), with an annual correlation of 81 percent between the observed and computed volumes.

For Gage 6410 on Channel A, the computed results were low for water years 1985-87 and 1994-95. The computed results were high for water years 1993 and 1996-99. Overall, the 1985 through 1999 computed flows at Gage 6410 were only 0.3 percent lower in total volume (879,289 acre-feet observed versus 876,880 acre-feet computed), with a high annual correlation (87 percent) between the observed and computed volumes.

### 5.4.4. Hurricane Lake Subwatershed

Gages 6390 and 6340 are located on the Little Coulee within the Hurricane Lake subwatershed. Gage 6390 provides data through water year 1997, while Gage 6340 covers water years 1998 and 1999, when Gage 6390 went into backwater.

#### 5.4.4.1. *Calibration Results*

For Gage 6390 (1985-97) and Gage 6340 (1998-99) on Little Coulee, the computed results were low for water years 1994-98. The computed results were high for water years 1986-87, 1993, and 1999 (see Appendix D). Overall, the 1985 through 1999 computed flows at Gage 6100 were only 0.1 percent higher in total volume (179,435 acre-feet observed versus 179,650 acre-feet computed), with an annual correlation of 53 percent between the observed and computed volumes.

#### 5.4.4.2. *Discussion – Annual Correlation Value*

The annual volume correlation in the Hurricane Lake subwatershed was significantly lower than the other subwatersheds in the Devils Lake upper basin. The calibration process, including the lower correlation, seemed to indicate that the potential storage volume in the subwatershed was being underestimated. There are two main factors that may have contributed to this underestimation. First, the Hurricane Lake subwatershed is completely within the 10-foot contour interval area, where NWI polygons make up 84 percent of the total depression count. The NWI polygons typically represent a smaller area than the maximum depression area (see Section 3.5.1). As shown in Table 3-5 (see Section 3), the estimated depression area for the Hurricane Lake subwatershed made up approximately 12 percent of the total subwatershed area. In contrast, the subwatersheds within the 5-foot contour interval area had depression area estimates between 18 and 21 percent of the total depression area. However, the aerial photos showed that there was at least as much depression area in Hurricane Lake subwatershed compared to the other subwatersheds. Therefore, the total depression area and storage is being underestimated to some extent.

The second factor is the underestimation of lake storage volume in the subwatershed. Half of the 18 lakes in the upper basin are located within the Hurricane Lake subwatershed, comprising approximately 40 percent of the total upper basin lake area. However, the DEM grid tends to underestimate the storage volume available in lakes, and storage-area curves were not available for any of the lakes in the Hurricane Lake subwatershed. (In contrast, storage-area curves were available for six of the nine lakes outside of the Hurricane Lake subwatershed).

Regardless of the possible reasons for the lower correlation, the overall flows affecting Devils Lake are not significantly impacted because the Hurricane Lake subwatershed contributes less than 9 percent of the total upper basin discharge volume to Devils Lake. In addition, for all but water years 1998 and 1999, a gage downstream of Hurricane Lake subwatershed was used for calibration (Gage 6400 on Big Coulee).

#### 5.4.5. Mauvais Coulee Subwatershed (Including Calio/St. Joe Coulee Subwatersheds)

For purpose of calibration, the Mauvais Coulee subwatershed model did not include the Mauvais 6100 area, which was modeled separately. However, the output discharge from the Mauvais 6100 area serves as an input to the Mauvais Coulee model. The ungaged Calio Coulee and St. Joe Coulee subwatersheds were modeled as part of the Mauvais Coulee subwatershed. The St. Joe Coulee subwatershed discharges into Mike's Lake, while the Calio Coulee subwatershed flows into Chain Lake. As part of the upper basin "Chain Lakes", Mike's Lake discharges into Chain Lake, which flows into Lake Alice, which in turn discharges into Lake Irvine. Lakes Alice and Irvine are located within the Mauvais Coulee subwatershed.

Gages 6400 and 6270 are located on the Big Coulee, downstream of Lake Irvine. Gage 6400 provides data through water year 1997, while Gage 6270 covers water years 1998 and 1999, when Gage 6400 went into backwater.

##### *5.4.5.1. Calibration Results*

At Gage 6400 and Gage 6270 on Big Coulee, the computed results were low for water years 1994-95, 1997, and 1999. The computed results were high for water years 1985-93, 1996, and 1998 (see Appendix D). Overall, the 1985 through 1999 computed flows were only 0.2 percent higher in total volume (1,161,908 acre-feet observed versus 1,164,149 acre-feet computed), with an annual correlation of 76 percent between the observed and computed volumes.

### 5.5. SUMMARY OF CALIBRATION RESULTS

A summary of results for each streamflow gage used in calibration is provided as Table 5-2. The table also includes the cumulative result of gaged inputs just upstream of Devils Lake, which includes the following gages, depending on water year:

Water Years 1985-97: Gage 6410 (Channel A) + Gage 6400 (Big Coulee)

Water Years 1998-99: Gage 6410 on Channel A + Gage 6270 (Big Coulee) + Gage 6340 (Little Coulee)

The total area draining to these gages represents all but 4 percent of the total upper basin watershed area. The annual correlation value for the gaged inputs was 85 percent.

Some of the differences seen in the calibration results may be attributed to the variation in precipitation patterns not captured by the number and location of the gages.

Table 5-2. Summary of calibration results.

| **Subwatershed** | **Calibration Gage(s)** | **Observed Volume** (acre-ft) | **Computed Volume** (acre-ft) | **Volume Difference** (%) | **Annual Correlation** (%) |
|---|---|---|---|---|---|
| Edmore Coulee | 6200 | 342,785 | 345,612 | + 0.8 | 88 |
| | 6215 | 311,011 | 312,244 | + 0.4 | 90 |
| Hurricane Lake | 6390/6340 | 179,435 | 179,650 | + 0.1 | 53 |
| Mauvais Coulee | 6400/6270 | 1,161,908 | 1,164,149 | + 0.2 | 76 |
| Mauvais 6100 | 6100 | 423,946 | 424,013 | + 0.02 | 79 |
| Starkweather Coulee | 6239 | 246,457 | 246,948 | + 0.2 | 81 |
| | 6410 | 879,289 | 876,880 | - 0.3 | 87 |
| *ALL GAGED INPUTS to Devils Lake* | *6410/6400, or 6410/6270/6340* | *2,093,065* | *2,124,308* | *+ 1.5* | *85* |

## 5.6. CALIBRATED PARAMETERS

### 5.6.1. Parameters Calibrated for Entire Upper Basin (Not Calibrated by Region)

One of the goals of the calibration process was to vary a minimal number of parameters by subwatershed, and to keep those parameters within a close range of realistic values for the Devils Lake upper basin. The following parameters were selected during the Mauvais 6100 test calibration and were left unchanged between subwatersheds and regions: percolation rate, upper zone depth, potential soil capacity, initial soil capacity, next day flow fraction. The values used for each of these parameters are listed in Table 5-3 below, in English units (metric values were used as input to the model).

The temperature threshold for transitioning to the High regime was set within a small range of 45˚ to 46˚ F during model calibration. The threshold temperature for transitioning to the Low regime was set to 35˚ F.

Table 5-3. Parameters calibrated for entire upper basin.

| Regime | Percolation Rate (in/hr) | Upper Zone Depth (in) | Potential Soil Capacity (in) | Initial Soil Capacity (in) | Next Day Flow Fraction | Threshold Temperature (˚ F) |
|---|---|---|---|---|---|---|
| Low | 0 | 0.39 | 13 | 9 | 0.1 | 35 |
| High | 0.0082 | 1.18 | 13 | 9 | 0.1 | 45 or 46 |

### 5.6.2. Parameters Calibrated by Region

The calibrated values for infiltration rate and evapotranspiration coefficient in each subwatershed and region are provided in Table 5-4. Infiltration rate is listed in both English and metric units, as the latter were used in the calibration process. The infiltration rate for the Low regime is between 0.0034 and 0.044 inches per hour (0.0021 and 0.027 meters per day). For the High regime, the infiltration rate ranges from 0.16 to 0.66 inches per hour (0.1 to 0.4 meters per day). These values are consistent with those reported for the various soil types in the Devils Lake upper basin (see Section 2.1.6). The evapotranspiration coefficient ranges from 0.76 to 0.95 in the Low regime and 0.83 to 0.95 in the High regime.

The calibrated parameters are similar (or the same) for many of the adjacent model regions in the upper basin watershed, including the following:

- Edmore Region 3 and Starkweather Region 2 (on east side of upper basin).
- Mauvais Regions 1 and 2 (i.e., St. Joe and Calio Coulee subwatersheds).
- Mauvais 6100 and Mauvais Region 3 (in the middle of the upper basin).
- Hurricane Lake, Comstock, and Mauvais Region 4 (on west side of upper basin).

Table 5-4. Parameters calibrated by region: Infiltration rate and ET coefficient.

| Model Area | Region | Regime | Infiltration Rate (in/hr) | Infiltration Rate (m/day) | ET Coefficient |
|---|---|---|---|---|---|
| Comstock | 1 | Low | 0.041 | 0.025 | 0.95 |
| | | High | 0.66 | 0.4 | 0.95 |
| Hurricane Lake | 1 | Low | 0.041 | 0.025 | 0.95 |
| | | High | 0.66 | 0.4 | 0.95 |
| Mauvais Coulee | 1 | Low | 0.021 | 0.0125 | 0.90 |
| | | High | 0.33 | 0.2 | 0.95 |
| | 2 | Low | 0.021 | 0.0125 | 0.90 |
| | | High | 0.33 | 0.2 | 0.95 |
| | 3 | Low | 0.005 | 0.003 | 0.77 |
| | | High | 0.18 | 0.11 | 0.90 |
| | 4 | Low | 0.044 | 0.027 | 0.95 |
| | | High | 0.66 | 0.4 | 0.95 |
| Mauvais 6100 | 1 | Low | 0.003 | 0.0021 | 0.77 |
| | | High | 0.16 | 0.1 | 0.86 |
| Edmore Coulee | 1 | Low | 0.033 | 0.02 | 0.76 |
| | | High | 0.59 | 0.36 | 0.95 |
| | 2 | Low | 0.013 | 0.008 | 0.76 |
| | | High | 0.26 | 0.16 | 0.83 |
| | 3 | Low | 0.013 | 0.008 | 0.76 |
| | | High | 0.56 | 0.34 | 0.95 |
| Starkweather Coulee | 1 | Low | 0.022 | 0.0137 | 0.76 |
| | | High | 0.66 | 0.4 | 0.95 |
| | 2 | Low | 0.013 | 0.008 | 0.76 |
| | | High | 0.56 | 0.34 | 0.95 |

## 5.7. COMPARISON WITH USGS HYDROLOGIC STUDY OF STARKWEATHER COULEE

The USGS conducted a study of surface-water runoff and storage in the Starkweather Coulee subwatershed using the Precipitation-Runoff Modeling System (PRMS) (Vining, report to be released). The USGS study area was located upstream of Gage 6239 on Starkweather Coulee. A comparison of total depression area and volume is presented in Section 3.5.2. The USGS study area is slightly larger than the area in the WEST study (262 versus 252 mi$^2$), which may result from differences in the algorithm used for watershed delineation.

A comparison of computed versus observed runoff volumes reveals the same general year-to-year pattern in both studies. For both models, the computed runoff volume was less than observed for water years 1985-97, 1989, 1992, and 1994-95. The computed volume was greater than observed for water years 1990, 1993, and 1996-98. Only during the very low runoff water years of 1988 and 1991 was a similar pattern not seen.

In the USGS model, the computed runoff for water year 1993 was somewhat higher than observed, while water years 1994-95 were slightly low in total volume. In the WEST model, the computed runoff for water year 1993 was much higher than observed. However, this was offset by the computed runoff for water years 1994-95 being much lower than observed. As a result, the cumulative computed runoff for water years 1993-95 was only 3 percent higher than the observed value.

The annual volume correlation for the USGS model was 89 percent (calibration period: 1981-98), while the correlation for the WEST model was 81 percent (calibration period: 1985-99). The lower correlation value is primarily a result of previously mentioned water years 1993-95. While not part of the USGS study area, the correlation for the WEST study was 87 percent at the Starkweather Coulee subwatershed outlet (Gage 6410 on Channel A).

Differences between the USGS and WEST models of the Starkweather Coulee Gage 6239 subarea include the following:

- Precipitation data – The USGS model used data from Edmore, Devils Lake, and Langdon gages, plus additional data from the North Dakota Atmospheric Resource Board observation network. WEST used data from only the Edmore and Cando gages.

- Parameter variation – In the USGS model, parameters such as soil water-holding capacity were varied over 50 hydrologic response units (subbasins). The WEST model used the same set of parameters throughout the entire Gage 6239 subarea.

- Snowmelt algorithm – There were differences in the snowmelt calculation by the USGS's PRMS model and the HEC-1 degree-day method used by the WEST model.

## 5.8. COMPARISON WITH CALIBRATION OF NWS HYDROLOGIC MODEL

The NWSRFS snow and Sacramento soil moisture models from the National Weather Service (NWS) were calibrated in a previous study in order to make better advance predictions of Devils Lake levels (Anderson, 1998). The NWS described their calibration results for a number of gages and events. With the exception of the Channel A (Gage 6410) calibration, nearly all of the results presented were also observed in the WEST study. In the NWS study, Dry and Morrison Lake level data are used in calibration, which improved matching in some years (e.g., 1987 and 1993). The WEST calibration did not use lake level data, although it did have an 87 percent correlation at Gage 6410).

The gage calibration results for both models are described below:

- Edmore Region 1 (Gage 6200) – The major runoff event in summer of 1993 was overestimated by both models. The NWS calibration report states that the Edmore gage likely received more rain in this event than the basin as a whole.

- Edmore Region 2 (Gage 6215) – The spring snowmelt in 1987 was underestimated by both models. The volume of the summer of 1993 event was slightly underestimated by both models. The peak rainfall for this event most likely occurred over this region (Anderson, 1998).

- Starkweather Region 1 (Gage 6239) – Both models underestimated the spring snowmelt for 1987 and 1992, and overestimated the 1993 summer runoff.

- Hurricane Lake (Gage 6390) – This subwatershed was described as the “most difficult basin to model” (Anderson, 1998). The NWS’s initial simulation of the subwatershed was conducted using parameters from the Mauvais 6100 subarea (Gage 6100 at Cando). This yielded computed volumes 400 percent of observed. The WEST model also overpredicted the runoff by the same magnitude when the parameters from the Mauvais 6100 model were used. Both models also had a tendency to underestimate higher flows, while underestimating lower flows. It is likely that lakes in the Hurricane Lake subwatershed were affecting the runoff in a manner that is not being captured by either model.

# 6. ALTERNATIVE ANALYSES

The primary purpose of this study is to assess the impacts of upper basin storage restoration alternatives on the inflows to Devils Lake. The upper basin storage alternative under consideration is the restoration of drained depressions. Due to lack of data, the storage capacity of the upper basin lakes was not explicitly modeled. This storage component would have a value of 28,590 acre-feet by raising the outlets of existing lakes and 5,761 acre-feet from new dam construction (North Dakota State Water Commission, 1999). Since these volumes are within the range of volumes modeled for depression storage, the effects of increasing storage in the upper basin lakes is bracketed by the results of depression restoration scenarios.

The depressions described as “possibly drained” in this report may be fully drained, mostly drained, partially drained, likely drained (i.e., appears drained, but not definitively so), filled-in, or otherwise non-intact or non-functional. The clear presence of a man-made drain was not a prerequisite for classifying a depression as “possibly drained”. In a similar manner, depressions labeled as “possibly intact” could be fully intact, mostly intact, or likely intact (i.e., appears intact, but not definitively so). The presence of standing water was not a prerequisite for classifying a depression as “possibly intact” because water in a shallow depression could be fully lost to evaporation.

Eleven climatic scenarios were used to simulate future conditions with and without depression restoration. Possibly drained depressions having an average depth of greater than or equal to 0.5 feet were candidates for restoration. Different levels of restoration (25, 50, 75, and 100 percent by volume of the restoration candidates) were analyzed. These levels of restoration were selected to provide a range of analysis results that could be used by others to evaluate the feasibility of restoration on an economic or other basis.

For those scenarios with less than 100 percent restoration, the restoration candidates were chosen randomly rather than using optimization by drainage area or location. Though not considered in this study, additional volume could be retained in each depression by constructing berms, gated structures, or tie backs to higher ground.

When a depression was restored, the total depression volume to the pour point was restored. Since the contributing drainage areas are modeled for each of the depressions (see Section 4), only the runoff from the area that drains to the depression fills the depression. Some depressions may have large contributing areas that may cause overtopping whereas some depressions may not. Depending on the depression surface area and evaporation rate, the amount of storage carry-over from year to year will vary with the depression characteristics. Generally, the annual available depression storage is less than the total depression storage.

The climate sequences, restoration scenarios and simulation results are described in the following sections.

## 6.1. Climate Sequences

Eleven (11) climatic scenarios were used to simulate future conditions. This was done by substituting historical climatic data for water years 1980 through 1999 (evaporation, precipitation, and temperature) into the future water years. A wet scenario (water years 1993 to 1999 repeated over and over again) and ten 20-year climate sequences were modeled. The ten climate sequences will be used by the USGS in their stochastic analysis of inflows to Devils Lake. Table 6-1 shows how historic water years 1980 through 1999 were used in the ten 20-year future climatic sequences (arranged vertically in the table).

Table 6-1. Historical water years used for each climate sequence.

| Simulated Water Year | Climate Sequence | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 001 | 002 | 003 | 004 | 005 | 006 | 007 | 008 | 009 | 010 |
| 2001 | 1981 | 1994 | 1998 | 1992 | 1980 | 1999 | 1986 | 1989 | 1982 | 1990 |
| 2002 | 1983 | 1999 | 1997 | 1995 | 1986 | 1989 | 1999 | 1989 | 1999 | 1988 |
| 2003 | 1991 | 1995 | 1982 | 1985 | 1983 | 1985 | 1994 | 1996 | 1996 | 1997 |
| 2004 | 1995 | 1986 | 1998 | 1995 | 1982 | 1991 | 1996 | 1982 | 1988 | 1997 |
| 2005 | 1985 | 1981 | 1984 | 1996 | 1997 | 1980 | 1999 | 1982 | 1989 | 1996 |
| 2006 | 1986 | 1981 | 1990 | 1986 | 1991 | 1992 | 1995 | 1991 | 1991 | 1994 |
| 2007 | 1997 | 1987 | 1999 | 1988 | 1994 | 1989 | 1983 | 1997 | 1995 | 1988 |
| 2008 | 1994 | 1992 | 1983 | 1995 | 1988 | 1995 | 1989 | 1982 | 1986 | 1984 |
| 2009 | 1999 | 1982 | 1986 | 1985 | 1987 | 1997 | 1986 | 1994 | 1992 | 1986 |
| 2010 | 1993 | 1985 | 1995 | 1998 | 1997 | 1980 | 1990 | 1991 | 1982 | 1988 |
| 2011 | 1998 | 1986 | 1989 | 1994 | 1998 | 1986 | 1987 | 1989 | 1997 | 1981 |
| 2012 | 1983 | 1986 | 1990 | 1982 | 1998 | 1991 | 1999 | 1987 | 1984 | 1987 |
| 2013 | 1980 | 1997 | 1994 | 1991 | 1986 | 1991 | 1983 | 1985 | 1994 | 1986 |
| 2014 | 1989 | 1989 | 1990 | 1991 | 1997 | 1984 | 1982 | 1995 | 1992 | 1985 |
| 2015 | 1983 | 1987 | 1989 | 1994 | 1993 | 1991 | 1987 | 1983 | 1997 | 1994 |
| 2016 | 1996 | 1994 | 1996 | 1994 | 1994 | 1989 | 1985 | 1982 | 1986 | 1987 |
| 2017 | 1994 | 1993 | 1987 | 1980 | 1992 | 1987 | 1996 | 1987 | 1990 | 1985 |
| 2018 | 1997 | 1995 | 1999 | 1986 | 1994 | 1999 | 1995 | 1988 | 1992 | 1999 |
| 2019 | 1998 | 1998 | 1986 | 1984 | 1982 | 1989 | 1986 | 1984 | 1981 | 1996 |
| 2020 | 1986 | 1992 | 1991 | 1998 | 1998 | 1984 | 1989 | 1985 | 1987 | 1985 |

Table 6-2 lists which water years may be considered “dry”, “wet”, or “moderate” for each climate sequence. The classification of each water year (1980-99), which was provided by the USGS, is based on the annual streamflow at the Starkweather Coulee gage. This criterion was selected because the gage is centrally located in the basin and is not affected by upstream lakes. Based on this criterion, the breakdown of dry, wet, and moderate water years is as follows:

Dry: 1984, 1988-91
Wet: 1993, 1995-97, 1999
Moderate: 1980-83, 1985-87, 1992, 1994, 1998

Table 6-2. Climatic condition for each water year and climate sequence.

| SIMULATED WATER YEAR | CLIMATE SEQUENCE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 001 | 002 | 003 | 004 | 005 | 006 | 007 | 008 | 009 | 010 |
| 2001 | MOD | MOD | MOD | MOD | MOD | **WET** | MOD | **DRY** | MOD | **DRY** |
| 2002 | MOD | **WET** | **WET** | **WET** | MOD | **DRY** | **WET** | **DRY** | **WET** | **DRY** |
| 2003 | **DRY** | **WET** | MOD | MOD | MOD | MOD | MOD | **WET** | **WET** | **WET** |
| 2004 | **WET** | MOD | MOD | **WET** | MOD | **DRY** | **WET** | MOD | **DRY** | **WET** |
| 2005 | MOD | MOD | **DRY** | **WET** | **WET** | MOD | **WET** | MOD | **DRY** | **WET** |
| 2006 | MOD | MOD | **DRY** | MOD | **DRY** | MOD | **WET** | **DRY** | **DRY** | MOD |
| 2007 | **WET** | MOD | **WET** | **DRY** | MOD | **DRY** | MOD | **WET** | **WET** | **DRY** |
| 2008 | MOD | MOD | MOD | **WET** | **DRY** | **WET** | **DRY** | MOD | MOD | **DRY** |
| 2009 | **WET** | MOD | MOD | MOD | MOD | **WET** | MOD | MOD | MOD | MOD |
| 2010 | **WET** | MOD | **WET** | MOD | **WET** | MOD | **DRY** | **DRY** | MOD | **DRY** |
| 2011 | MOD | MOD | **DRY** | MOD | MOD | MOD | MOD | **DRY** | **WET** | MOD |
| 2012 | MOD | MOD | **DRY** | MOD | MOD | **DRY** | **WET** | MOD | **DRY** | MOD |
| 2013 | MOD | **WET** | MOD | **DRY** | MOD | **DRY** | MOD | MOD | MOD | MOD |
| 2014 | **DRY** | **DRY** | **DRY** | **DRY** | **WET** | **DRY** | MOD | **WET** | MOD | MOD |
| 2015 | MOD | MOD | **DRY** | MOD | **WET** | **DRY** | MOD | MOD | **WET** | MOD |
| 2016 | **WET** | MOD | **WET** | MOD | MOD | **DRY** | MOD | MOD | MOD | MOD |
| 2017 | MOD | **WET** | MOD | MOD | MOD | MOD | **WET** | MOD | **DRY** | MOD |
| 2018 | **WET** | **WET** | **WET** | MOD | MOD | **WET** | **WET** | **DRY** | MOD | **WET** |
| 2019 | MOD | MOD | MOD | **DRY** | MOD | **DRY** | MOD | **DRY** | MOD | **WET** |
| 2020 | MOD | MOD | **DRY** | MOD | MOD | **DRY** | **DRY** | MOD | MOD | MOD |

In the simulations, the model was first run using historical data for water years 1979 through 2000 (i.e. October 1, 1978, through September 30, 2000) to determine the soil and depression storage conditions on October 1, 2000 (i.e., water year 2001), which is the beginning of the future simulations. Water years 1979 through 1984 were included as a model warm-up period before running water years 1985 through 1999 to be consistent with the procedures used during the model calibration. Depression restoration was implemented October 1, 2002 (i.e. water year 2003).

## 6.2. DEPRESSION RESTORATION SCENARIOS

All possibly drained depressions having an average depth greater than or equal to 0.5 feet were considered candidates for restoration. Table 6-3 summarizes the possibly drained depressions by average depth for the entire upper basin (i.e., Comstock, Hurricane Lake, Mauvais, Calio, St. Joe, Starkweather and Edmore subwatersheds). Breakdowns by subwatershed are provided in Appendix C.

There are 13,464 restoration candidates (26 percent of the total number of possibly drained depressions) having a total surface area of 79,762 acres (86 percent of the total possibly drained depression surface area) and a total volume of 127,835 acre-feet (96 percent of the total possibly drained depression volume).

Table 6-3. Summary of possibly drained depressions.

| **AVERAGE DEPTH (ft)** | **POSSIBLY DRAINED DEPRESSIONS** | | | | | |
|---|---|---|---|---|---|---|
| | **Count** | **Area** (acres) | **Volume** (acre-feet) | **% Count** | **% Area** | **% Volume** |
| $d_{avg} < 0.5$ | 38,746 | 12,667 | 4,894 | 74.2% | 13.7% | 3.7% |
| $0.5 \le d_{avg} < 1$ | 9,196 | 25,228 | 18,936 | 17.6% | 27.3% | 14.3% |
| $1 \le d_{avg} < 1.5$ | 2,376 | 19,396 | 23,965 | 4.6% | 21.0% | 18.1% |
| $1.5 \le d_{avg} < 2$ | 995 | 13,833 | 24,249 | 1.9% | 15.0% | 18.3% |
| $2 \le d_{avg} < 3$ | 688 | 14,581 | 35,050 | 1.3% | 15.8% | 26.4% |
| $3 \le d_{avg} < 4$ | 172 | 5,506 | 18,904 | 0.3% | 6.0% | 14.2% |
| $4 \le d_{avg} < 5$ | 29 | 705 | 3,125 | 0.06% | 0.8% | 2.4% |
| $d_{avg} \ge 5$ | 8 | 512 | 3,606 | 0.02% | 0.6% | 2.7% |
| ***Total Candidates for Restoration ($d_{avg}$ >= 0.5)*** | ***13,464*** | ***79,762*** | ***127,835*** | **25.8%** | **86.3%** | **96.3%** |
| *Total All Possibly Drained Depressions* | *52,210* | *92,429* | *132,729* | | | |

Of the 13,464 possibly drained depressions that were restoration candidates, a total of 79 depressions were at or below elevation 1,447 feet msl. Although included, these depressions would presumably become inundated should the water level in Devils Lake rise to 1,447 feet. These 79 depressions had a surface area of 1,544 acres (1.9 percent of total area of restoration candidate pool), and a volume of 2,814 acre-feet (2.2 percent of the volume of the total volume of the restoration candidate pool). In the following discussion, restoration volume refers only to the volume available from the restoration candidate pool.

The four restoration scenarios are described in Table 6-4.

Table 6-4. Summary of restoration levels

| **Restoration Scenarios** | **Description** |
|---|---|
| A | The original model, as calibrated. No restoration. |
| B | 25 percent (31,431 acre-ft) of the total restoration volume is converted from possibly drained to possibly intact. |
| C | 50 percent (63,608 acre-ft) of the total restoration volume is converted from possibly drained to possibly intact. |
| D | 75 percent (94,850 acre-ft) of the total restoration volume is converted from possibly drained to possibly intact. |
| E | 100 percent (127,835 acre-ft) of the total restoration volume is converted from possibly drained to possibly intact (e.g., all restoration candidates are converted from possibly drained to possibly intact). |

Depressions were restored in each subwatershed. Each subwatershed had the same percentage of restored volume as the corresponding restoration scenario. For example, for 50 percent restoration (Scenario C), 50 percent by volume of the possibly drained depressions from Comstock was restored and 50 percent by volume of the possibly drained depressions from Starkweather was restored and so forth for each subwatershed.

The scenarios were constructed by **randomly** selecting depressions that had been classified as possibly drained, and converting these depressions to possibly intact. The selection process was not optimized by drainage area or location. To construct the 25 percent restoration scenario model (Scenario B), enough restoration candidate depressions were randomly chosen in each subwatershed modeled until 25 percent of the total volume of restoration candidates was achieved for that subwatershed. These were converted to possibly intact depressions. To construct the 50 percent restoration scenario model (Scenario C), additional depressions, randomly selected, were added to this set until 50 percent of the total restoration volume was achieved for each subwatershed. The 100 percent restoration scenario (Scenario E) models had all restoration candidates reclassified as possibly intact.

Table 6-5 provides a summary of the surface area and volume restored in each restoration scenario. A detailed breakdown of restored depressions versus average depth is provided in Appendix E.

Table 6-5. Summary of restored area and volume.

| RESTORATION LEVEL | 25% (Scenario B) | 50% (Scenario C) | 75% (Scenario D) | 100% (Scenario E) |
|---|---|---|---|---|
| Area Restored, acres | 19,472 | 39,681 | 59,872 | 79,762 |
| Volume Restored, acre-ft | 31,431 | 63,608 | 94,850 | 127,835 |

All simulations started on October 1, 1978, with the original calibration geometry (with no restoration candidates converted to possibly intact). When the simulation date reached the restoration transition date (October 1, 2002), the appropriate depressions were converted to possibly intact.

## 6.3. DISCUSSION OF RESULTS

This section presents a summary of the future simulation results, followed by a brief analysis of these results. Tables 6-6 through 6-9 provide a summary of the simulation results for each of the restoration levels, by simulation number (climate sequence). These tables include runoff totals for water year 2003 to the end of simulation. The annual runoff reduction for each restoration scenario is shown in Figures 6-1, 6-2, 6-3, and 6-4, for climate sequences 001 (representing high runoff), 002 (moderate runoff), and 004 (low runoff), and the WET scenario, respectively. More complete results, including an annual breakdown by water year for each simulation, are provided in Appendix E-2. The runoff values in the tables represent combined model output from Channel A, Big Coulee and the Comstock subwatershed.

Table 6-6. Runoff for 25 percent restoration (Scenario B, 31,431 acre-ft restored).

| Climate Sequence | No Restoration Total Runoff (acre-ft) | 25% Restoration Total Runoff (acre-ft) | Total Runoff Reduction (acre-ft) | As % of No Restoration Total Runoff | Average Annual Runoff Reduction (acre-ft) |
|---|---|---|---|---|---|
| 001 | 3,101,720 | 2,970,420 | 131,300 | 4% | 7,294 |
| 002 | 2,017,254 | 1,890,207 | 127,047 | 6% | 7,058 |
| 003 | 1,688,607 | 1,567,761 | 120,846 | 7% | 6,714 |
| 004 | 1,292,294 | 1,181,596 | 110,698 | 9% | 6,150 |
| 005 | 2,888,905 | 2,747,266 | 141,640 | 5% | 7,869 |
| 006 | 1,279,228 | 1,177,336 | 101,892 | 8% | 5,661 |
| 007 | 2,259,557 | 2,126,439 | 133,118 | 6% | 7,395 |
| 008 | 1,594,247 | 1,475,432 | 118,815 | 7% | 6,601 |
| 009 | 1,632,394 | 1,503,675 | 128,720 | 8% | 7,151 |
| 010 | 2,051,472 | 1,935,128 | 116,344 | 6% | 6,464 |
| Average | 1,980,568 | 1,857,526 | 123,042 | 6% | 6,836 |
| WET | 8,737,679 | 8,475,026 | 262,653 | 3% | 7,959 |

Note: Runoff and runoff reduction values are for water years 2003 through 2020 (for climate sequences 001 through 010, and their average), or water years 2003 through 2035 (for the WET climate sequence).

Table 6-7. Runoff for 50 percent restoration (Scenario C, 63,608 acre-ft restored).

| Climate Sequence | No Restoration Total Runoff (acre-ft) | 50% Restoration Total Runoff (acre-ft) | Total Runoff Reduction (acre-ft) | As % of No Restoration Total Runoff | Average Annual Runoff Reduction (acre-ft) |
|---|---|---|---|---|---|
| 001 | 3,101,720 | 2,849,602 | 252,118 | 8% | 14,007 |
| 002 | 2,017,254 | 1,774,335 | 242,919 | 12% | 13,496 |
| 003 | 1,688,607 | 1,460,855 | 227,752 | 13% | 12,653 |
| 004 | 1,292,294 | 1,081,622 | 210,672 | 16% | 11,704 |
| 005 | 2,888,905 | 2,614,470 | 274,435 | 9% | 15,246 |
| 006 | 1,279,228 | 1,095,893 | 183,335 | 14% | 10,185 |
| 007 | 2,259,557 | 2,007,321 | 252,236 | 11% | 14,013 |
| 008 | 1,594,247 | 1,363,807 | 230,440 | 14% | 12,802 |
| 009 | 1,632,394 | 1,400,535 | 231,860 | 14% | 12,881 |
| 010 | 2,051,472 | 1,833,479 | 217,993 | 11% | 12,111 |
| Average | 1,980,568 | 1,748,192 | 232,376 | 12% | 12,910 |
| WET | 8,737,679 | 8,221,460 | 516,219 | 6% | 15,643 |

Note: Runoff and runoff reduction values are for water years 2003 through 2020 (for climate sequences 001 through 010, and their average), or water years 2003 through 2035 (for the WET climate sequence).

Table 6-8. Runoff for 75 percent restoration (Scenario D, 94,850 acre-ft restored).

| Climate Sequence | No Restoration Total Runoff (acre-ft) | 75% Restoration Total Runoff (acre-ft) | Total Runoff Reduction (acre-ft) | As % of No Restoration Total Runoff | Average Annual Runoff Reduction (acre-ft) |
|---|---|---|---|---|---|
| 001 | 3,101,720 | 2,728,151 | 373,569 | 12% | 20,754 |
| 002 | 2,017,254 | 1,679,984 | 337,271 | 17% | 18,737 |
| 003 | 1,688,607 | 1,369,477 | 319,130 | 19% | 17,729 |
| 004 | 1,292,294 | 987,935 | 304,359 | 24% | 16,909 |
| 005 | 2,888,905 | 2,487,449 | 401,457 | 14% | 22,303 |
| 006 | 1,279,228 | 1,024,103 | 255,125 | 20% | 14,174 |
| 007 | 2,259,557 | 1,904,466 | 355,092 | 16% | 19,727 |
| 008 | 1,594,247 | 1,268,483 | 325,764 | 20% | 18,098 |
| 009 | 1,632,394 | 1,306,784 | 325,611 | 20% | 18,090 |
| 010 | 2,051,472 | 1,736,267 | 315,205 | 15% | 17,511 |
| Average | 1,980,568 | 1,649,310 | 331,258 | 17% | 18,403 |
| WET | 8,737,679 | 7,962,113 | 775,567 | 9% | 23,502 |

Note: Runoff and runoff reduction values are for water years 2003 through 2020 (for climate sequences 001 through 010, and their average), or water years 2003 through 2035 (for the WET climate sequence).

Table 6-9. Runoff for 100 percent restoration (Scenario E, 127,835 acre-ft restored).

| Climate Sequence | No Restoration Total Runoff (acre-ft) | 100% Restoration Total Runoff (acre-ft) | Total Runoff Reduction (acre-ft) | As % of No Restoration Total Runoff | Average Annual Runoff Reduction (acre-ft) |
|---|---|---|---|---|---|
| 001 | 3,101,720 | 2,612,598 | 489,122 | 16% | 27,173 |
| 002 | 2,017,254 | 1,590,623 | 426,632 | 21% | 23,702 |
| 003 | 1,688,607 | 1,273,595 | 415,012 | 25% | 23,056 |
| 004 | 1,292,294 | 902,813 | 389,481 | 30% | 21,638 |
| 005 | 2,888,905 | 2,357,316 | 531,589 | 18% | 29,533 |
| 006 | 1,279,228 | 949,983 | 329,245 | 26% | 18,291 |
| 007 | 2,259,557 | 1,802,293 | 457,265 | 20% | 25,404 |
| 008 | 1,594,247 | 1,174,346 | 419,901 | 26% | 23,328 |
| 009 | 1,632,394 | 1,208,589 | 423,805 | 26% | 23,545 |
| 010 | 2,051,472 | 1,642,059 | 409,412 | 20% | 22,745 |
| Average | 1,980,568 | 1,551,421 | 429,146 | 22% | 23,841 |
| WET | 8,737,679 | 7,708,322 | 1,029,357 | 12% | 31,193 |

Note: Runoff and runoff reduction values are for water years 2003 through 2020 (for climate sequences 001 through 010, and their average), or water years 2003 through 2035 (for the WET climate sequence).

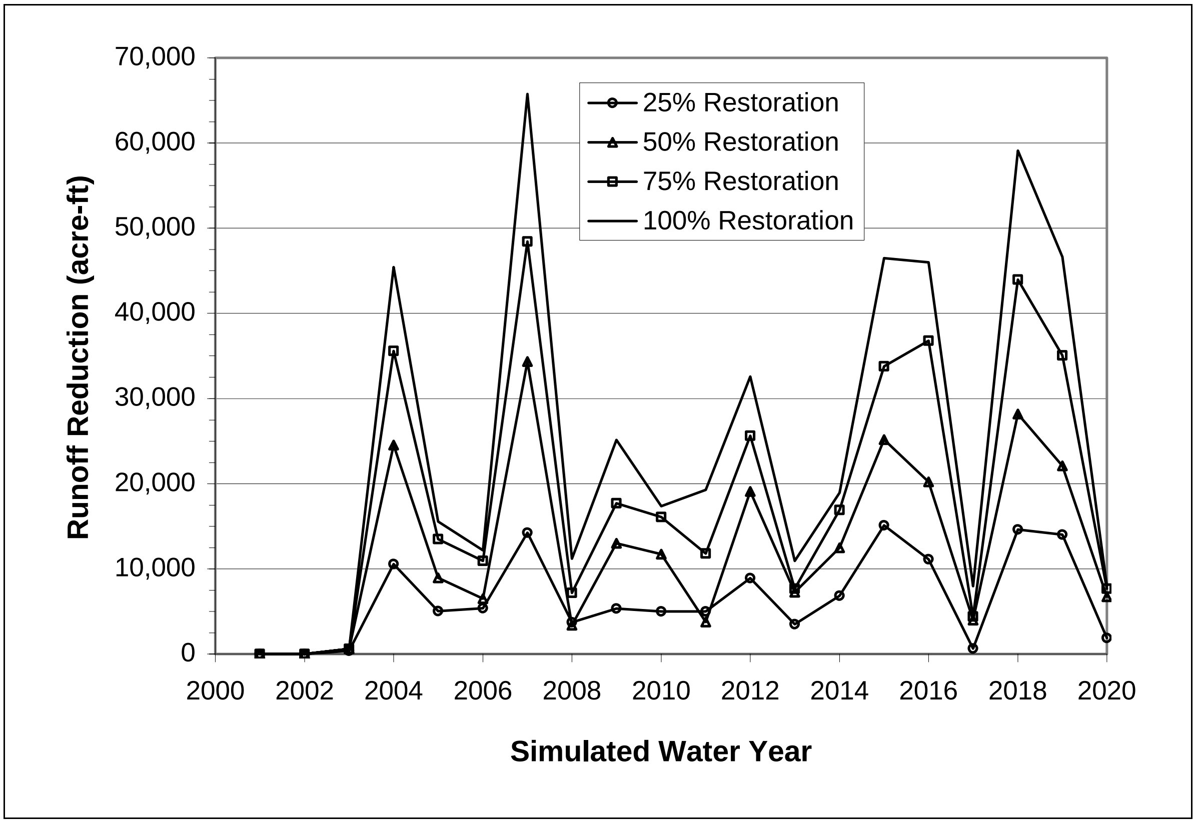



Figure 6-1. Annual runoff reduction for climate sequence 001 (high runoff).

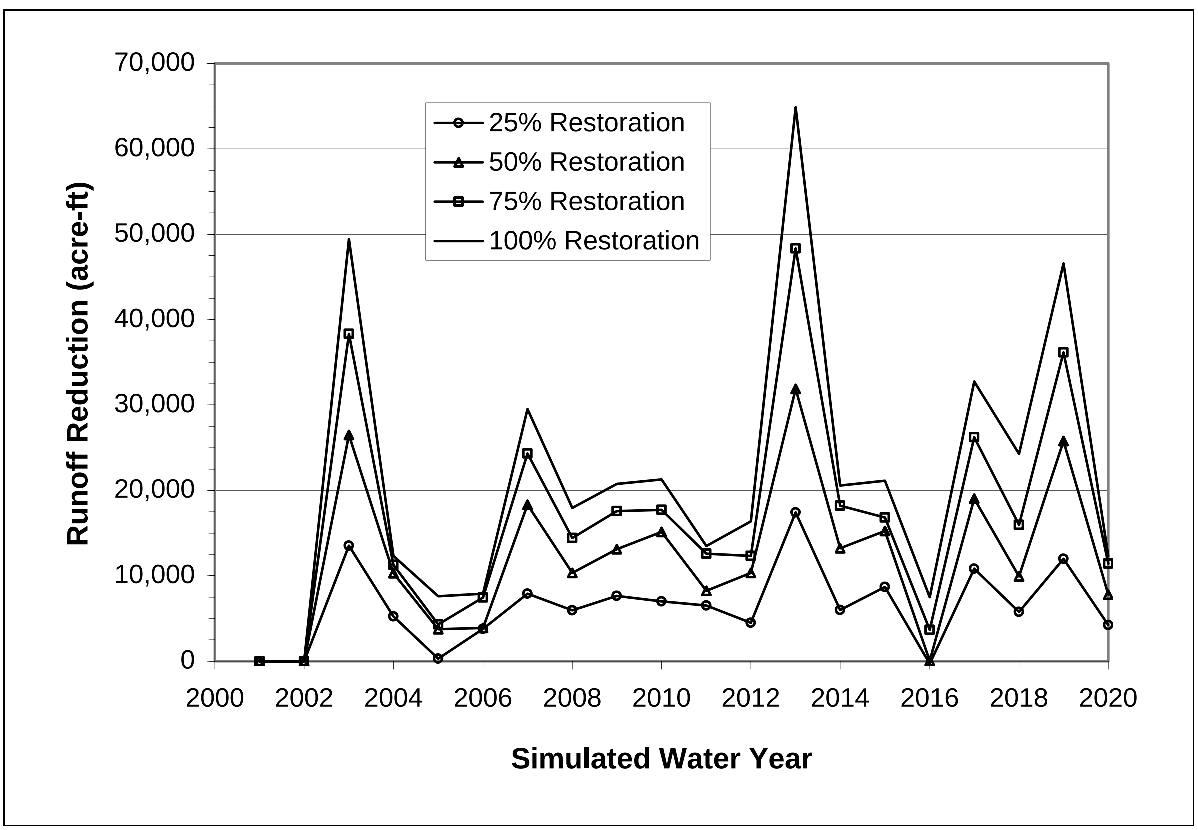



Figure 6-2. Annual runoff reduction for climate sequence 002 (moderate runoff).

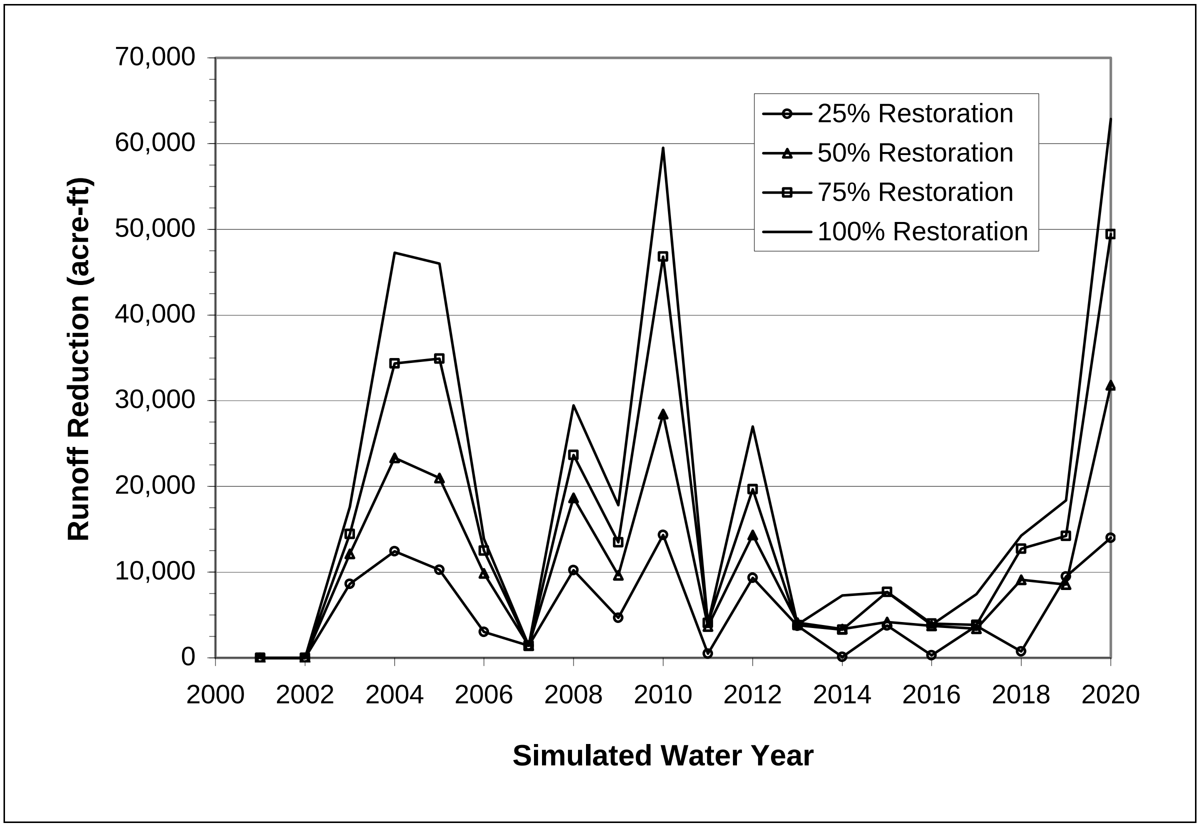



Figure 6-3. Annual runoff reduction for climate sequence 004 (low runoff).

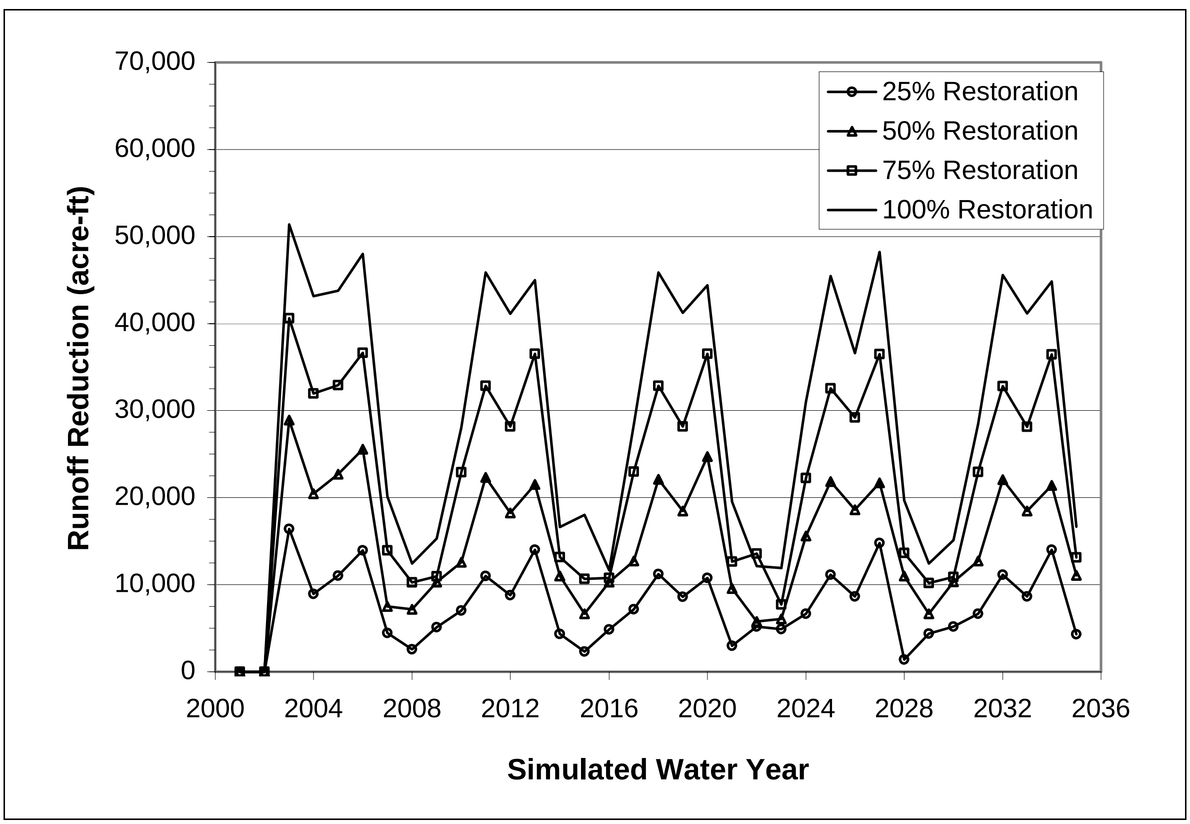



Figure 6-4. Annual runoff reduction for WET climate sequence.

The above tables and figures show how the restoration of possibly drained depressions affects the annual runoff volume. As depressions are added in the restoration levels, a portion of the non-depression surface area is converted to possibly intact depression surface area. In addition, the storage volume of possibly intact depressions increases as depressions are restored. The increased surface area of these possibly intact depressions results in a greater amount of free water surface evaporation. However, the increase in depression surface area reduces the amount of soil available for infiltration and evapotranspiration of infiltrated water. Therefore, the increase in free water surface evaporation is partly offset by a reduction in water lost to evapotranspiration. The reduction in evapotranspiration is significant. The weighted average of the evapotranspiration constants (the evapotranspiration of saturated soil as percentage of free water-surface evaporation) used in the model was 0.93 for the summer season, when most of the evaporation occurs. These constants were set as part of the PRINET model calibration given the precipitation, streamflow and Devils Lake evaporation values. With the evapotranspiration constants used in calibration, the evapotranspiration rates were close to the rates of free water surface evaporation.

As shown in Figures 6-1 through 6-4, the annual flow reductions vary significantly for individual water years (also see tables in Section E-2 of Appendix E). Table 6-10 shows the average annual runoff reduction for each restoration scenario and climate sequence. The actual annual reduction in the inflows for each climatic and restoration scenario are included in Appendix E. The average annual capture is less that the restored volume. For example, at the 25 percent restoration level, there is an average flow reduction of 6,836 acre-feet per year. For simulation sequences 1 through 10, this corresponds to 22 percent of the restored volume (31,431 acre-feet). Notice that this number remains relatively constant across the restoration scenarios, decreasing slightly as the restoration level increases. Even at the 100 percent restoration level, there is an average 19 percent reduction in annual flow as a percentage of the restoration volume. The average annual capture is slightly higher for the wet simulation compared to the climate sequences 001 through 010. The average annual capture is consistently about 25 percent of the restored volume across the different restoration scenarios.

Another way of presenting the impact of restoration on runoff reduction is through the ratio of the reduction in annual runoff volume to the area restored. For example, for the 25 percent restoration level (B), the average runoff reduction is 6,826 acre-ft. Since 19,472 acres were restored, this yields 6,826 acre-ft / 19,472 acres = 0.3506 feet = 4.21 inches. This value primarily represents the difference between the storage and evaporation in the restored depressions and the percolation and evapotranspiration from the soil area before restoration. It does not represent the average evaporation from a depression, which was approximately 20 or more inches per year.

Table 6-10. Summary of average runoff reductions due to restoration.

| | | No Restoration | | Restoration Level | | | |
|---|---|---|---|---|---|---|---|
| | | | | **25%** (B, 31,431 acre-ft and 19,472 acres restored) | **50%** (C, 63,608 acre-ft and 39,681 acres restored) | **75%** (D, 94,850 acre-ft and 59,872 acres restored) | **100%** (E, 127,835 acre-ft and 79,762 acres restored) |
| **Climate Sequence** | **Water Years** | **Total Runoff** (acre-ft) | **Average Annual Runoff** (acre-ft) | **Average Annual Runoff Reduction** (acre-ft) | | | |
| 001 | 2003-2020 | 3,101,720 | 172,318 | 7,294 | 14,007 | 20,754 | 27,173 |
| 002 | 2003-2020 | 2,017,254 | 112,070 | 7,058 | 13,496 | 18,737 | 23,702 |
| 003 | 2003-2020 | 1,688,607 | 93,812 | 6,714 | 12,653 | 17,729 | 23,056 |
| 004 | 2003-2020 | 1,292,294 | 71,794 | 6,150 | 11,704 | 16,909 | 21,638 |
| 005 | 2003-2020 | 2,888,905 | 160,495 | 7,869 | 15,246 | 22,303 | 29,533 |
| 006 | 2003-2020 | 1,279,228 | 71,068 | 5,661 | 10,185 | 14,174 | 18,291 |
| 007 | 2003-2020 | 2,259,557 | 125,531 | 7,395 | 14,013 | 19,727 | 25,404 |
| 008 | 2003-2020 | 1,594,247 | 88,569 | 6,601 | 12,802 | 18,098 | 23,328 |
| 009 | 2003-2020 | 1,632,394 | 90,689 | 7,151 | 12,881 | 18,089 | 23,545 |
| 010 | 2003-2020 | 2,051,472 | 113,971 | 6,464 | 12,111 | 17,511 | 22,745 |
| Average | | 1,980,568 | 110,032 | 6,836 | 12,910 | 18,403 | 23,841 |
| As Percent of Restored Volume | | | | 22% | 20% | 19% | 19% |
| Runoff Reduction Volume / Area Restored | | | | 4.2 in | 3.9 in | 3.7 in | 3.6 in |
| WET | 2003-2035 | 8,737,679 | 264,778 | 7,959 | 15,643 | 23,502 | 31,193 |
| As Percent of Restored Volume | | | | 25% | 25% | 25% | 24% |

Shown in Table 6-11 are the average annual changes in evaporation and evapotranspiration across climatic sequences 1 through 10, for each of the restoration levels. Detailed evaporation and storage results for each climate sequence and subwatershed are provided in Appendix E-3 (average annual volumes in acre-ft), and Appendix E-4 (average annual volumes in inches, normalized by area).

Table 6-11. Average annual evaporation and evapotranspiration for climatic sequences 001 through 010, during simulated years 2003-2020.

| **Restoration Level** | **Average Annual Evaporation from Depressions** (acre-ft) | **Increase in Depression Evaporation vs. No Restoration** (acre-ft) | **Average Annual Soil ET** (acre-ft) | **Decrease in Soil ET versus No Restoration** (acre-ft) | **Decrease in ET, as % of Increase in Depression Evaporation** |
|---|---|---|---|---|---|
| 0% (no restoration) | 407,930 | - | 1,975,981 | - | - |
| 25% | 440,859 | 32,929 | 1,949,513 | 26,468 | 80% |
| 50% | 474,285 | 66,355 | 1,921,860 | 54,121 | 82% |
| 75% | 507,019 | 99,089 | 1,894,378 | 81,603 | 82% |
| 100% | 539,143 | 131,213 | 1,867,320 | 108,661 | 83% |

The model predicts that between 80 and 83 percent of the increase in depression evaporative losses that occur from the restored depressions would have occurred anyway from evapotranspiration from the unrestored soil area. This is water that would have infiltrated and eventually been lost through evapotranspiration had the depressions not been there to collect the water. Note that the increase in evaporation minus the decrease in evapotranspiration is very close to, but not exactly equal to, the average reduction in runoff volumes. Runoff volumes are also affected by percolation and net changes in water storage in the basin.

### 6.3.1. Effect of Depression Evaporation on Runoff Reduction

The PRINET model did not include a soil moisture algorithm beneath the depressions. Instead, the depressions were modeled as hard-bottom "bowls". Consequently, infiltration of water from a depression into the soil and evapotranspiration from the soil in the dry portions of a depression (when the depression was less than 100 percent full) were not modeled. Therefore, the model could be underpredicting the net total evaporation (free surface evaporation plus evapotranspiration from the soil) in the depressions.

For climatic sequences 001 through 010, the average wetted surface area of the depressions as a percentage of total depression area was approximately 69 percent. Therefore, on the average, 31 percent of the area of the depressions was not undergoing either evaporation or evapotranspiration. It follows that a model revision to include infiltration and evapotranspiration in the soil area of depressions could result in additional runoff reduction.

### 6.3.2. Underprediction of Runoff Reduction Values

Given the current classifications of "possibly intact" and "possibly drained" depressions, the runoff reduction values reported in this study are conservative for two reasons:

(1) The depressions restored in the 25, 50, and 75 percent restoration scenarios were selected randomly within each subwatershed. The restoration level was uniform across

all subwatersheds (e.g., for the 25 percent restoration scenario, 25 percent by volume of the restoration candidates in the Comstock subwatershed was restored, 25 percent by volume of restoration candidates in Edmore was restored, and so forth for each subwatershed). Incremental optimization of the depressions selected for restoration was not performed. It is expected that the runoff reduction volumes would increase for the scenarios having less than 100 percent restoration if the restoration candidates were selected using an optimization routine (i.e., determine which depressions would result in the largest runoff reduction). Potential optimizations include selection by contributing drainage areas, by location (restoring depressions in subwatersheds having high runoff and a larger percentage of "possibly drained" depressions or restoring on-river depressions before off-river), and by depression size or volume.

(2) Since the net total evaporation from the depressions was probably underpredicted (see Section 6.3.1), the annual runoff reduction with depression restoration could be underestimated.

### 6.3.3. Recommendations for Future Studies

The goal of this study was to evaluate the impacts of upper basin storage on the volume of runoff entering Devils Lake. A hydrologic model, PRINET, was developed in accordance with the study goals and project constraints. The results of this study indicate that depression restoration can reduce the volume of runoff entering Devils Lake. Because of the model limitations discussed previously, the runoff reduction values reported in this study are considered to be conservative. Further studies should be conducted to more accurately quantify the runoff reduction resulting from depression restoration. Making refinements to the PRINET model and optimizing the selection of restoration candidates are recommended.

## 6.4. IMPACTS OF RESTORATION ON DEVILS LAKE ELEVATION

The generated runoff data for the 10 randomly selected climate scenarios will be used by the USGS and Corps to evaluate the potential effect of upper basin storage restoration on future lake levels of Devils Lake. This will be done in two stages. In stage one, the generated runoff data from each of the climate scenarios will be input into the USGS lake simulation model to compute 10 future lake level traces for each of the restoration levels (0, 25, 50, 75, and 100 percent), assuming no constructed outlet from Devils Lake. Future flood damages and restoration costs (discounted to present-worth) will be computed for each of the traces and used to estimate the mean benefit-cost ratio for each restoration level. A graphical analysis will be used to determine the restoration level with the highest benefit-cost ratio. The wet scenario also will be analyzed to determine the potential effect of storage restoration for preventing a natural spill into the Sheyenne River under very wet conditions.

In the second stage of analysis, the generated runoff data for the 10 climate scenarios will be used to adjust Devils Lake inflows for 10,000 generated 50-year lake level traces from the USGS stochastic lake level simulation model. The USGS stochastic model was developed using existing conditions. Thus, the 10,000 traces represent the full range of possible future lake levels during the next 50 years assuming no upper-basin storage restoration. A large number of traces are required in the stochastic model in order to evaluate the probability of occurrence of extreme events, such as a natural spill from Devils Lake to the Sheyenne River, over the 50-year project-planning horizon. To evaluate the potential effect of upper basin storage restoration both with and without a constructed outlet, inflows for each of the 10,000 stochastic traces will be adjusted to approximate the effects of upper-basin storage restoration. Using inflow data from the 10 climate scenarios described above, a nonlinear regression model will be developed by the USGS for predicting the reduction in runoff due to storage restoration. Preliminary analysis by the USGS (personal communication, A.V. Vecchia) indicate that runoff reduction in any particular year and for any particular restoration level can be approximated using "natural" (with no restoration) runoff, the concurrent year's open-water (May-November) evaporation and precipitation for Devils Lake, and the preceding year's open-water evaporation and precipitation for Devils Lake.

The adjusted inflow data from the second stage will be used to generate 10,000 lake-level "futures" under 4 project scenarios: 1) no storage restoration and no outlet, 2) storage restoration with no outlet, 3) outlet with no storage restoration, and 4) storage restoration with outlet. The 10,000 futures will be used to perform probabilistic benefit-cost analysis of an outlet in conjunction with upper basin storage restoration.

### 6.4.1. Data Provided to USGS

Monthly flows in acre-feet were provided to USGS for the three outlets of the model into Devils Lake (Channel A, Big Coulee, and Comstock), as well as twelve other concentration points, requested by the USGS, internal to the Devils Lake watershed. These flows were provided for all 11 climate sequences and 5 restoration scenarios (11 sequences for each of the 5 restoration scenarios totaling 55 different simulations for each subwatershed). The USGS will adjust the ungaged flows to Devils Lake appropriately using the results for the Comstock subwatershed.

Table 6-12. Flow locations for monthly flows provided to USGS.

| Point Number | Location |
|---|---|
| 1 | Channel A |
| 2 | Big Coulee |
| 3 | Comstock |
| 4 | Hurricane Lake |
| 5 | Inflow to Dry Lake |
| 6 | Inflow to Mike's Lake |
| 7 | Outflow from Mike's Lake |
| 8 | Inflow to Chain Lake |
| 9 | Outflow from Chain Lake |
| 10 | Inflow to Lake Alice |
| 11 | Outflow from Lake Alice |
| 12 | Inflow to Lake Irvine |
| 13 | Outflow from Lake Irvine |
| 14 | Flow at stream gage 05056270 |
| 15 | Flow at stream gage 05056400 |

# 7. RECOMMENDATIONS FOR FUTURE STUDIES

The objective of this study was to evaluate the impacts of upper basin storage (i.e., depression storage) on the volume of runoff entering Devils Lake. This analysis included the following steps:

1. Depression delineation and classification.

2. Development of a hydrologic model having the ability to simulate soil and depression storage.

3. Calibrate the hydrologic model to historical data.

4. Run the calibrated hydrologic model for various future simulations to compute the reduction in runoff volume for various levels of depression restoration.

Given the limitations in the available data and other project constraints, some simplifications and assumptions were made to complete the above process. Since the results of this study indicate that depression restoration can reduce the volume of runoff entering Devils Lake, further studies should be conducted to more accurately quantify the runoff reduction resulting from depression restoration. The recommendations for future studies are discussed in the following sections.

## 7.1. DEPRESSION DELINEATION AND CLASSIFICATION

An estimate of the volume of intact and drained depressions was required for the hydrologic analysis. The depression delineation and classification completed as part of this study was extensive, physically-based (i.e., minimal extrapolation), reproducible and conducted based upon the study objective. The results of the depression delineation and classification are reasonable estimates of "possibly intact" and "possibly drained" depression area and volume. However, the accuracy of the delineation and classification of some of the individual depressions was limited by the available data and project constraints. In future studies, this work could be refined as follows:

- Obtain historical aerial photos, preferably from the 1950's when drainage activity was minimal, to assist in identifying depressions in those areas missed both by the DEM grid and NWI data. These historical photos could also be compared to current photos to verify the depression classification.

- Perform extensive field verification to locate drainage ditches, determine the functionality of the farmed depressions, and verify the depression classification.

- Utilize the 1997 color infrared photography, which is higher resolution than the DOQ's used in this study, to refine the depression delineation and classification, but this would be very labor intensive because the data is not available in digital format.

- Obtain more refined soil data to develop relationships between depression area and hydric soils.

- Include more classifications such as “partly drained”. Separate depressions that have drainage ditches from those that have been disturbed by other activities such as farming.

- Obtain higher resolution digital terrain data, especially in those areas currently modeled from the 10-foot contour interval data.

## 7.2. HYDROLOGIC MODEL

A hydrologic model, PRINET, was developed in accordance with the study goals to simulate soil and depression storage in the Devils Lake basin. Some simplified algorithms for depression storage and evaporation, snowmelt and frozen ground were incorporated into the model. These algorithms were appropriate for this study. However, the following model refinements are recommended for more detailed analyses:

- The PRINET model did not include a soil moisture algorithm beneath the depressions. Instead, the depressions were modeled as hard-bottom “bowls”. Consequently, infiltration of water from a depression into the soil and evapotranspiration from the soil in the dry portions of a depression (when the depression was less than 100 percent full) were not modeled. Therefore, the model could be underpredicting the net total evaporation (free surface evaporation plus evapotranspiration from the soil) in the depressions. A soil moisture accounting algorithm with infiltration and evapotranspiration should be added to the model.

- The Devils Lake evaporation was applied to the depression. Since the depressions are significantly smaller water bodies, the depression evaporation may differ from the Devils Lake evaporation. Some evaporation measurements for different depression sizes would be useful in determining the rate of evaporation from the depressions compared to pan evaporation measurements and the evaporation from Devils Lake.

- A relationship of surface area versus storage was developed for the depressions (see Section 3). This relationship was in the envelope of area-storage curves provided for several of the upper basin lakes. The digital elevation models could be used to refine the area-storage relationships of the depressions.

- The degree-day method was used to simulate snowmelt in PRINET. A more rigorous energy budget algorithm could be developed if the required data are available.

- An infiltration/season break was incorporated in the model to simulate frozen and unfrozen ground conditions (i.e., low and high infiltration conditions). A 30-day moving average of the average daily temperature is used to transition between the two conditions. The volume of runoff is very sensitive to the infiltration break. A more physically-based algorithm should be incorporated into the hydrologic model.

If the hydrologic model is modified, the model must be re-calibrated to observed data before it is used to evaluate depression restoration.

## 7.3. HYDROLOGIC MODEL CONSTRUCTION AND CALIBRATION

There were only six precipitation gages having complete records in the 2,616 square mile study area. There can be a considerable amount of variation in the precipitation and storm tracks within this watershed (personal communication with Dr. Leon Osborne). The model calibration could be improved if more precipitation data were available.

## 7.4. DEPRESSION RESTORATION

For the restoration scenarios with less than 100 percent depression restoration, the restoration candidates were selected randomly within each subwatershed. Incremental optimization of the depressions selected for restoration was not performed. It is expected that the runoff reduction volumes associated with depression restoration would increase if an optimization routine was used to select the depressions for restoration. Potential optimization parameters are contributing drainage area, depression location, and depression size or volume. Though not considered in this study, additional volume could be retained in each depression by constructing berms, gated structures, or tie backs to higher ground.

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